Proceedings of the First Symposium on REMOTE SENSING OF ENVIRONMENT

13, 14, 15 February 1962

INFRARED LABORATORY
Institute of Science and Technology
THE UNIVERSITY OF MICHIGAN

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Ann Arbor, Michigan

NOTICES

Sponsorship. This symposium was conducted by the Institute of Science and Technology for the U. S. Office of Naval Research. Contract NOnr 1224(44). Contracts and grants to The University of Michigan for the support of sponsored research by the Institute of Science and Technology are administered through the Office of the Vice-President for Research.

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FOREWORD

The first symposium on remote sensing of environment was held on 13, 14, and 15 February 1962 at The University of Michigan campus. The symposium was conducted in conjunction with a study program currently in progress at The University of Michigan's Institute of Science and Technology. The purpose of this study program is to explore possible applications of remote sensing techniques to the various earth science fields. This study program is sponsored by the Office of Naval Research through funds made available by the Army, Navy, and Air Force (Contract NOnr 1224(44)).

The overall purpose of the symposium was to review the current state of the art of remote sensing technology and, by way of informal discussion, to encourage comments and suggestions from the various professional fields represented. The first two days of this symposium were devoted to discussion of the technology and applicability of remote sensing equipments and techniques, and the last day to the preparation and dissemination of brief working papers by the participating earth scientists divided into three working groups. These working papers indicated the main lines of interest of the particular working groups and suggested possible applications for the remote sensing techniques discussed during the first two days.

The Proceedings contains transcripts of the introductory remarks, manuscripts of the scheduled talks, transcripts of the informal discussions, and the statements prepared by the three working groups.

In order to distribute these Proceedings as rapidly as possible, we have simply transcribed the tape-recorded sessions and have edited the results only where this appeared to be essential for clarity. When passages were edited, care was taken to retain all essential content and to preserve the context of all talks and comments. Editorial notes appear within the text in square brackets where deemed appropriate. In most cases these notes refer to slides or blackboard drawings which were used during the symposium but which were not available for inclusion within this document. Some notes caution the reader concerning passages where interpretation of

the tape recordings was in doubt. It should be emphasized that the various speakers have not had the opportunity of editing their own material. Consequently, the conversational tone of the talks remains. We ask the reader's pardon for the inevitable imperfections caused by using transcriptions to produce documents.

The interest and enthusiasm exhibited by the participants has redoubled our desire to get these Proceedings published promptly and to proceed apace to answer the questions, fulfill the requests, and tackle some of the problems defined in the course of the sessions.

PARTICIPANTS IN
FIRST SYMPOSIUM ON REMOTE SENSING

Walter H. Bailey
Geography Branch
Office of Naval Research
Washington 25, D. C.

Frederick L. Bartman
Aeronautical and Astronautical Engineering
University of Michigan

William S. Benninghoff
Department of Botany
University of Michigan

Wendell A. Blikken
Radar Laboratory
Institute of Science and Technology
University of Michigan

Fred O. Briggson
Resident Representative
Office of Naval Research
University of Michigan

Norman Burns
Information Office
Institute of Science and Technology
University of Michigan

Lucian W. Chaney
Aeronautical and Astronautical Engineering
University of Michigan

Robert N. Colwell
Department of Forestry
The University of California
Berkeley 4, California

John M. DeNoyer
Acoustics and Seismics Laboratory
Institute of Science and Technology
University of Michigan

Joseph P. Dobell
Department of Geology and Geological Engineering
Michigan College of Mining and Technology
Houghton, Michigan

Floyd C. Elder
Meteorology Group
Department of Engineering Mechanics
University of Michigan

Donald E. Eschman, Head
Department of Geology
University of Michigan

William Fischer
Branch of Theoretical Geophysics
U. S. Geological Survey
Washington 25, D. C.

Dale S. Fisher
Infrared Laboratory
Institute of Science and Technology
University of Michigan

Guy Franceschini
Department of Oceanography and Meteorology
Texas A and M
College Station, Texas

Robert Frost
U. S. Army Corps of Engineers
Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

Robert M. Garrels
Division of Geological Sciences
Harvard University
Cambridge 38, Massachusetts

William Garrison
Department of Geography
Northwestern University
Evanston, Illinois

Marvin R. Holter
Infrared Laboratory
Institute of Science and Technology
University of Michigan

Linn Hoover
National Academy of Science -
National Research Council
Washington, D. C.

Leslie M. Jones
Aeronautical and Astronautical
Engineering
University of Michigan

Yale Katz
Planetary Science Department
The Rand Corporation
1700 Main Street
Santa Monica, California

George Kish
Department of Geography
University of Michigan

Peter M. Kuhn
U. S. Weather Bureau
Department of Meteorology
University of Wisconsin
Madison, Wisconsin

James Latham
Department of Geography
Bowling Green University
Bowling Green, Ohio

Laurence H. Lattman
Department of Geology
The Pennsylvania State University
University Park, Pennsylvania

John A. Leese
Meteorology Group
Department of Engineering Mechanics
University of Michigan

Hoyt Lemons
Army Research Office
Arlington Hall Station
Arlington 12, Virginia

James E. Lesch
Office of Research Administration
University of Michigan

Dale Liepper
Department of Oceanography and
Meteorology
Texas A and M
College Station, Texas

W. D. McClellan
Crops Protection Research Branch
United States Department of
Agriculture
Beltsville, Maryland

James McFadden
Department of Meteorology
University of Wisconsin
Madison, Wisconsin

James H. McLerran
U. S. Army Corps of Engineers
Cold Regions Research and Engineering
Laboratory
Hanover, New Hampshire

Carl D. Miller
Infrared Laboratory
Institute of Science and Technology
University of Michigan

Carlton E. Molineux
Terrestrial Sciences Laboratory
Geophysics Research Directorate
Air Force Cambridge Research
Laboratory
Bedford, Massachusetts

Joseph O. Morgan
Infrared Laboratory
Institute of Science and Technology
University of Michigan

Robert M. Moxham
Branch of Theoretical Geophysics
Geological Survey
Washington 25, D. C.

Alan Nichols
Conductron Corporation
Ann Arbor, Michigan

Vincent E. Noble
Meteorology Group
Department of Engineering Mechanics
University of Michigan

Robert L. Ohlsson, Associate Director
Institute of Science and Technology
University of Michigan

Charles E. Olson
Department of Forestry
University of Illinois
Urbana, Illinois

Herman O. Pardes
United States Army Signal Corps
Signal Research and Development Laboratory
Fort Monmouth, New Jersey

Dana C. Parker
Infrared Laboratory
Institute of Science and Technology
University of Michigan

Fabian C. Polcyn
Infrared Laboratory
Institute of Science and Technology
University of Michigan

Donald J. Portman
Meteorology Group
Department of Engineering Mechanics
University of Michigan

R. A. Ragotzkie
Department of Meteorology
University of Wisconsin
Madison, Wisconsin

Richard G. Ray
Earth Sciences Division
National Science Foundation
Washington 25, D. C.

Jack N. Rinker
U. S. Army Corps of Engineers
Cold Regions Research and Engineering Laboratory
Hanover, New Hamshire

John F. Riordan, Head
Computation Department
Institute of Science and Technology
University of Michigan

Robert E. Ruhe
U. S. Department of Agriculture
Soil Conservation Service
Ames, Iowa

Edward Ryznar
Meteorology Group
Department of Engineering Mechanics
University of Michigan

Bernard B. Scheps
U. S. Army Corps of Engineers
Geodesy Intelligence and Mapping
Research and Development Agency
Fort Belvoir, Virginia

J. Ralph Shay, Head
Department of Botany and Plant Pathology
Purdue University
Lafayette, Indiana

Harold Sherman
Office of the Director
Institute of Science and Technology
University of Michigan

Paul Sherr
Department of Meteorology and Geophysics
Bendix Systems Division
Ann Arbor, Michigan

James Skiles
Department of Electrical Enginerring
University of Wisconsin
Madison, Wisconsin

Elmer H. Smith, Head
Operations Research Department
Institute of Science and Technology
University of Michigan

Newbern Smith
Department of Electrical Engineering
University of Michigan

Stephan W. Spurr
Department of Forestry
University of Michigan

Gwynn H. Suits, Head
Infrared Laboratory
Institute of Science and Technology
University of Michigan

Waldo R. Tobler
Department of Geography
University of Michigan

Weston Vivian
Vice President of Engineering
Conductron Corporation
Ann Arbor, Michigan

David Q. Wark
Meteorological Satellite Laboratory
United States Department of Commerce
Weather Bureau
Washington 25, D. C.

Morris Weiss
Barnes Engineering Company
Stamford, Connecticut

James T. Wilson, Acting Director
Institute of Science and Technology
University of Michigan

James M. Wolf, Head
Sensory Subsystems Task
Institute of Science and Technology
University of Michigan

William L. Wolfe
Infrared Laboratory
Institute of Science and Technology
University of Michigan

Bart D. Woloson
Department of Civil Engineering
Northwestern University
Evanston, Illinois

Wendell Young
Navigation and Guidance Task
Institute of Science and Technology
University of Michigan

George J. Zissis
Infrared Laboratory
Institute of Science and Technology
University of Michigan

James H. Zumberge, Head
Glacial Geology and Polar Research
Laboratory
Institute of Science and Technology
University of Michigan

SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT

AGENDA

Michigan Union, Room 3S
University of Michigan
13-15 February 1962

0830	Registration:	
0930	Welcome:	Dr. Gwynn H. Suits, Head Infrared Laboratory Institute of Science and Technology
0945	Introduction:	Dr. J. T. Wilson, Acting Director Institute of Science and Technology
1015	Coffee Break	
1045	Basic Considerations Related to the Problem of Remote Sensing	Mr. Dana C. Parker Special Applications Group Infrared Laboratory Institute of Science and Technology
1200	Lunch	
1330	Airborne Geophysical Devices; State-of-the-Art and Applications	Mr. John M. DeNoyer Acoustics and Seismics Laboratory Institute of Science and Technology
1415	Radar Technology and Remote Sensing	Dr. Newbern Smith Professor of Electrical Engineering University of Michigan
1445	Discussion of Examples of Radar Imagery	Mr. Wendell Blikken Radar Laboratory Institute of Science and Technology
1515	Coffee Break	
1545	Informal Discussion Session	
1645	Adjourn	

WEDNESDAY

0900 Passive Microwave Technology and Remote Sensing

Dr. Weston Vivian
Vice President of Engineering
Conductron Corporation
Ann Arbor, Michigan

1015 Coffee Break

1045 Infrared Technology and Remote Sensing

Mr. Joseph Morgan
Special Applications Group
Infrared Laboratory
Institute of Science and Technology

1200 Lunch

1330 Aerial Photography - A Reappraisal of the Technology

Mr. Robert Frost, Chief
Photographic Interpretation Research Division
US Army Corps of Engineers
Cold Regions Research and Engineering Laboratory

1445 Coffee Break

1515 General Discussion of Remote Sensing Equipment

1600 Group Meetings

1700 Adjourn

THURSDAY

0900 Panel Discussion

1015 Coffee Break

1045 Panel Discussion

1200 Lunch

1330 The afternoon can be devoted to further informal discussion and recording of opinions and recommendations.

ABSTRACT

These *Proceedings* resulted from the first symposium on remote sensing of environment, held at The University of Michigan on 13, 14, and 15 February 1962. The purpose of the symposium was to review the current state of the art of remote sensing technology and to explore possible applications of this technology to the various earth science fields. These *Proceedings* contain both the discussions of the remote sensing techniques and the working papers written in response to these discussions by each of three working groups composed of the participating earth scientists.

WELCOME ADDRESS FOR THE REMOTE SENSING SYMPOSIUM

Gwynn Suits

I wish to welcome you to this special study on Remote Sensing of the Environment undertaken on behalf of the ONR by the University of Michigan. Since the dawn of man's history, eyesight and hearing have been his most powerful observational tools. The loss of these senses is such a serious matter that a person in primitive circumstances may fail to survive as a consequence. Sight and hearing arise from the sensing of radiant energy so the sensor need not be located adjacent to the disturbance. These senses are ideally suited to remote sensing, while touch, taste, and smell depend upon the transport of matter; and hence matter must be brought to the sensor or the sensor to the matter--a much more clumsy and slow process.

Yet as valuable as sight and hearing are, these senses are remarkably limited. They operate within very narrow pitch and chromatic intervals. Almost all of the turmoil of the earth is below the hearing range of our ears. Still, hearing covers about 10 octaves while sight covers barely one. We may blame our evolutional heritage for this. We are still creatures of the sea in many ways. Ancient sea water still flows in our veins and fills our eyes. This water is largely opaque to all electromagnetic radiation save those with wavelengths between .35 and .7 microns and of course the gamma rays which penetrate practically everything anyway.

Natural scientists have long been aware of these limitations. However, the modern natural scientist may be entirely unaware of the great strides which have been made in removing these limitations by remote sensing devices and techniques which were developed for military purposes and not publicized because of security regulations.

It is the purpose of this special study to examine, as far as security will allow, the potentiality of these new devices and techniques for advancing research in natural science. It is refreshing to a physical scientist to find an opportunity to apply to peaceful purposes those results of his research which have been a by product of military needs.

INTRODUCTION

James T. Wilson

Talking at the opening session of this symposium I would like to add to the welcome of Dr. Suits, my own personal welcome and the welcome of the Institute and the University. Technically it might have been more appropriate for me just to welcome you and for Dr. Suits and the people of his laboratory to make the opening remarks, but as I am an earth scientist that has been privileged to see some of the developments of the last few years that I think may affort many opportunities for the earth sciences, I am very happy to have a chance to say a few words this morning. I might first tell you a few words about the Institute at the University. I think that it is always nice when you attend meetings of this sort to know a little bit about the organization that you are visiting. The Institute of Science and Technology at the University of Michigan is a college-like structure within the University. We differ from the other colleges in that we give no credit courses but we feel ourselves very much a part of the educational structure. We try to lend some organization to many of the very large and diverse research programs of the University. Our faculty, if you want to call them that, are in part, faculty from other colleges within the University and in part research scientists on the Institute staff. Our students are students of the other colleges who work with us part-time and full-time on various research projects. Organizations of this sort, as I am sure that you are all aware, have become very much a part of the graduate educational pattern in the United States. Now the Institute is fairly heavily involved in the earth sciences at the University of Michigan. Our limnological and oceanographic programs at the University are centered in the Institute. Much of our work in polar studies and in seismology at the University is also a part of the Institute effort and we have various other ramifications into the earth sciences.

Geology and the rest of the earth sciences are one of the old but perpetually new fields of science. I am always fascinated by the fact that the early studies of the mathematical theory of heat flow were really first applied to the problems of geology. Much of the early work in radioactivity found an outlet in geological problems. At the present time, such things as carbon 14, isotope chemistry, and now I hope, the subject of the symposium, will find some real outlets in the fields of earth science. As I think you all know, a study by the National Academy of Science - National Research Council - ONR Group on the problem of remote sensing of the environment lead to the study contract here and this symposium is really the first visible effort of this study as Joe Morgan pointed out. While the University is well represented with the earth scientists, physicists, and engineers working in various areas and has helped in developing some of the sophisticated remote sensing devices that we hope will be of interest to earth scientists in general, we felt quite incompetent to make real headway on this problem without advice and council and suggestions from a group such as we have represneted here this morning. We wish to expose you to some of the state-of-the-art and to elicit from you suggestions, comments, and criticisms. We will try to tell you something about the present state of remote sensing techniques and hopefully you can tell us of potential applications. We also hope that you may be able to tell us of some of the things not yet done that would be of use to the earth sciences. Some of these may in some form or another already be underway somewhere.

When I see some of the data that is now available from remote sensing devices it is quite evident to me that these data certainly have very real application to the earth sciences, and I think that there is no question that the use of these data and the use of new data from various types of remote sensing devices should make possible some real giant steps forward in the earth sciences. We have, to a certain extent, exhausted the possibilities of many of the existing techniques. There are various sorts of quantum jumps in the state of geologic

knowledge that are related to techniques. I think perhaps those related to elucidation and understanding of principal are perhaps more important. New techniques also make possible some real advances. Speaking largely from the geological viewpoint, for that is my main field of knowledge, we can discuss certain of these. One of the early ones was the geological application of the information from bore holes. Then there is the well known application of physical measurements to the geological problems, measurements of gravity magnetic field, heat flow from the earth's interior, and so on. Most of these techniques involve in some way or another learning something about the properties of a material or its reaction to something to which it is subjected. I think that one of the real opportunities that may come out of remote sensing is the opportunity to look at large areas rapidly and to look at large areas in detail in a relatively short length of time. Some of the things that can be done in remote sensing can simultaneously give you both a better picture and a picture of a much larger area in a much shorter period of time than a single investigator or a team of investigators slowly combing over the ground on foot. As Dr. Suits pointed out our own built in remote sensing equipment is quite limited and we are forced to draw our conclusions only on the limited parts of the spectrum that we can sense. By interposing sophisticated remote sensing equipment we can enormously broaden the spectrum of information available to us.

What we ask from you is patience to listen to some presentations, many of which you will know as much or more about than we do but, we feel that it is essential that we try to expose the field as completely as possible in order to elicit from you any and all suggestions or advice that you can give us. Then our people working on the reports that come out of these symposia will end up with a document that should set this field of endeavor somewhat ahead. Then we can start soon, I hope, to cash in on some of the data that are available or that should soon be available.

SOME BASIC CONSIDERATIONS RELATED TO THE PROBLEM OF REMOTE SENSING

Dana Parker

Modern aircraft and earth satellites now make it possible to survey the earth from a vantage point heretofor unobtainable. Surveillance systems integrated into these vehicles make possible the rapid acquisition of geophysical data over large areas of the terrestrial environment. The output from these remote sensing devices can provide information of value to scientists and engineers in many different yet interrelated fields of endeavor. Already, with the aid of conventional apparatus, photographic pictures of great expanses of the cloud cover and land forms of the earth have been obtained. The possibilities inherent in the remote sensing of the earth and its environment are now greatly enhanced; one can begin to think in terms of coordinated investigations concerning the geological structure of the whole earth or of collecting data for a realistic assessment of the total heat budget. The problems which may ultimately find solutions in this way and the means for remote sensing which may lend itself to these tasks are subjects which have hardly been touched upon.

It is the purpose of this symposium to consider the capabilities of remote sensing devices and to consider possible applications to specific research problems. To accomplish this task we will first outline some of the basic problems involved in remote sensing. Then we will discuss the state-of-the-art of the different remote sensing devices that are available today. With this knowledge of the limitations and the capabilities of the various systems, we shall then try to determine what application people in the earth science field may have for the data generated by these remote sensors. We must broaden our thinking to cover the entire range of remoteness from the very low altitudes within the capability of manned

aircraft to the extremely high altitudes of artificial earth satellites. Then we must extend our thinking to cover the even more remote cases of lunar and planetary explorations.

Before we proceed further it may be well to define what we mean by remote sensing. Remote sensing is the measurement of some property of an object without having the measuring device physically in contact with the object. If we consider the properties of an object that make remote sensing possible, we find that they must present some disturbing influence at the point of detection. This disturbing influence then acts upon some ingeneous contrivance which the scientist has devised for detection or measurement, usually an energy transducer. If we study the physical properties of objects and try to set down all of the disturbing influences that they can convey to some remote point in space, we find that these are not too numerous taken categorically. Perhaps we can be allowed for the purpose of our discussion to lump these disturbing factors into two broad categories: 1) radiations, and 2) forces. Further for the simplification of our discussion we will not, with all due apologies to the theoretical physicists, allow our forces to influence our radiations and vice versa.

Since all objects having temperatures above absolute zero radiate electromagnetic energy by virtue of their atomic and molecular actions, and since this energy is radiated outward ad infinitum, requiring no propagating medium, we may sample the electromagnetic radiation properties of an object anywhere in the universe provided we have a suitably sensitive detector capable of intercepting a portion of the radiation. Likewise since all objects possess mass, we have the makings of potential force fields and here again we may measure this force by using an appropriate detector.

There are at least two ways that remote sensor data can be profitably used: in identifying objects or in determining something about a property of an object. Identification may be affected in a straightforward manner on the basis of shape, size, or other

criteria and may best be accomplished with a sensor that duplicates our visual senses, i.e., photography. The desired property of an object may be obtained directly or indirectly from the measurement that we make with a remote sensor. For example, in photography our sensor, the film, directly records levels of reflectivity of visible light. Indirectly we may then discern object shape or size. We may also use the discriminatory properties of reflectivity to determine such things as soil types or more specifically the relative ages of glacial till. In many cases the measurement we wish to make is the quantity, i.e., the absolute value of the radiation or force; while on the otherhand, we may wish to measure qualitative aspects, i.e., the relative value of the radiation or force, and thus acquire the information that this conveys in light of our knowledge of some of the physical properties of the object. The problem may be to determine the structural material of two buildings of identical shape; to determine the difference in rock type within a time-rock group; to determine the difference between healthy vegetation and diseased vegetation; to distinguish between soil types; to distinguish between snow and ice types; to determine thermal sources in regions of active faulting and vulcanism; to map ocean currents; to study net radiation and heat budget; to distinguish between clouds and land, water, or ice background; or to determine broad trends in the subsurface structure.

The problem of equipment design to accomplish the measurement of the desired disturbing influence will be discussed in subsequent lectures. Before we investigate the more gross technological problems associated with equipment design, however, it will be necessary to look at some of the various physical and environmental parameters that will affect the use of these remote sensing devices for scientific and engineering purposes.

Let us now look at the first category of remote sensors that we mentioned above--the sensors that sample some portion of the electromagnetic spectrum (Figure 1).

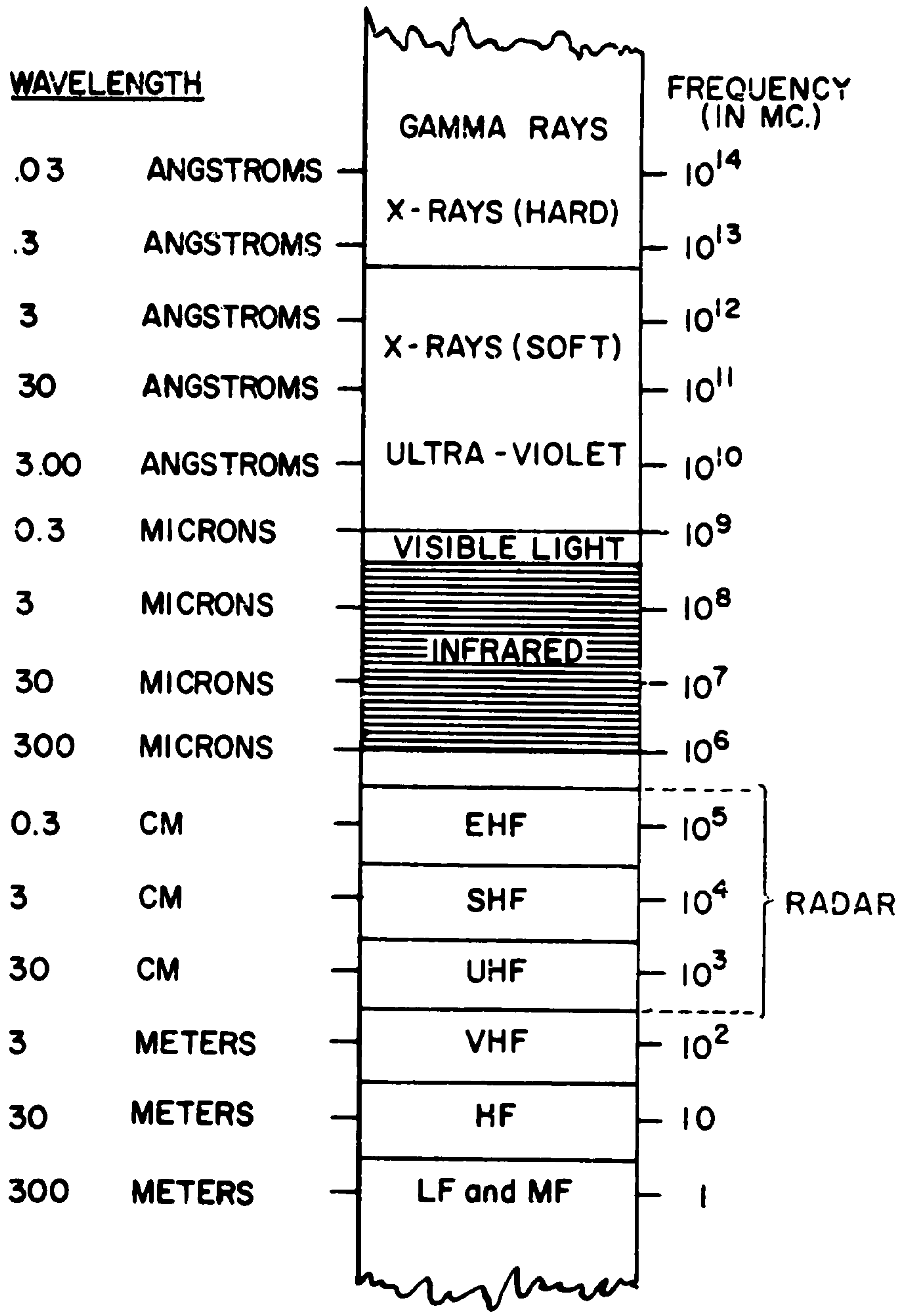

FIGURE 1 **Electromagnetic Spectrum**

Since these sensors are radiation detectors, we need to know something about the radiation properties of the source in the spectral region of concern; we need to know something about the medium through which the radiation is propagated, and we also need to know something about the detector and the method of displaying the detected radiation. During the course of the symposium, we shall be talking about both active and passive sensing systems and so it may be well to define these terms. An active system is one that actually illuminates the object under investigation with radiation of a particular wavelength and then samples the portion reflected back to the detecting device. Radar is perhaps the bext example of an active system among the radiation sensors. Night photography, where an artificial illumination system is required, would be another example. The passive system is one that merely samples emitted and/or reflected radiation from a source. Radiometers and scanners that measure emitted and reflected radiation in the infrared and microwave regions are examples of passive systems. Daylight photographic systems operating in the visible region are rather unique. They function as active systems because they rely upon an illuminating source, the sun. However, the illuminating source is not physically part of the system.

If we take a look at the distribution of radiant power throughout the electromagnetic spectrum for objects comparable to those on the earth surface (Figure 2), it may help to illustrate why we would wish to make use of both active and passive systems. Without going into too much basic detail, it will suffice to say that for a perfect radiator the power emitted per unit area is a function of the fourth power of the absolute surface temperature. It will absorb all radiation incident upon it and re-emit it as a function of its temperature. The radiant power distribution throughout the spectrum is in accordance with the Planck Radiation Law and the power peak shifts toward the shorter wavelengths as the temperature is increased. Looking at the power distribution curve for a perfect radiator at 300^{o}K, a

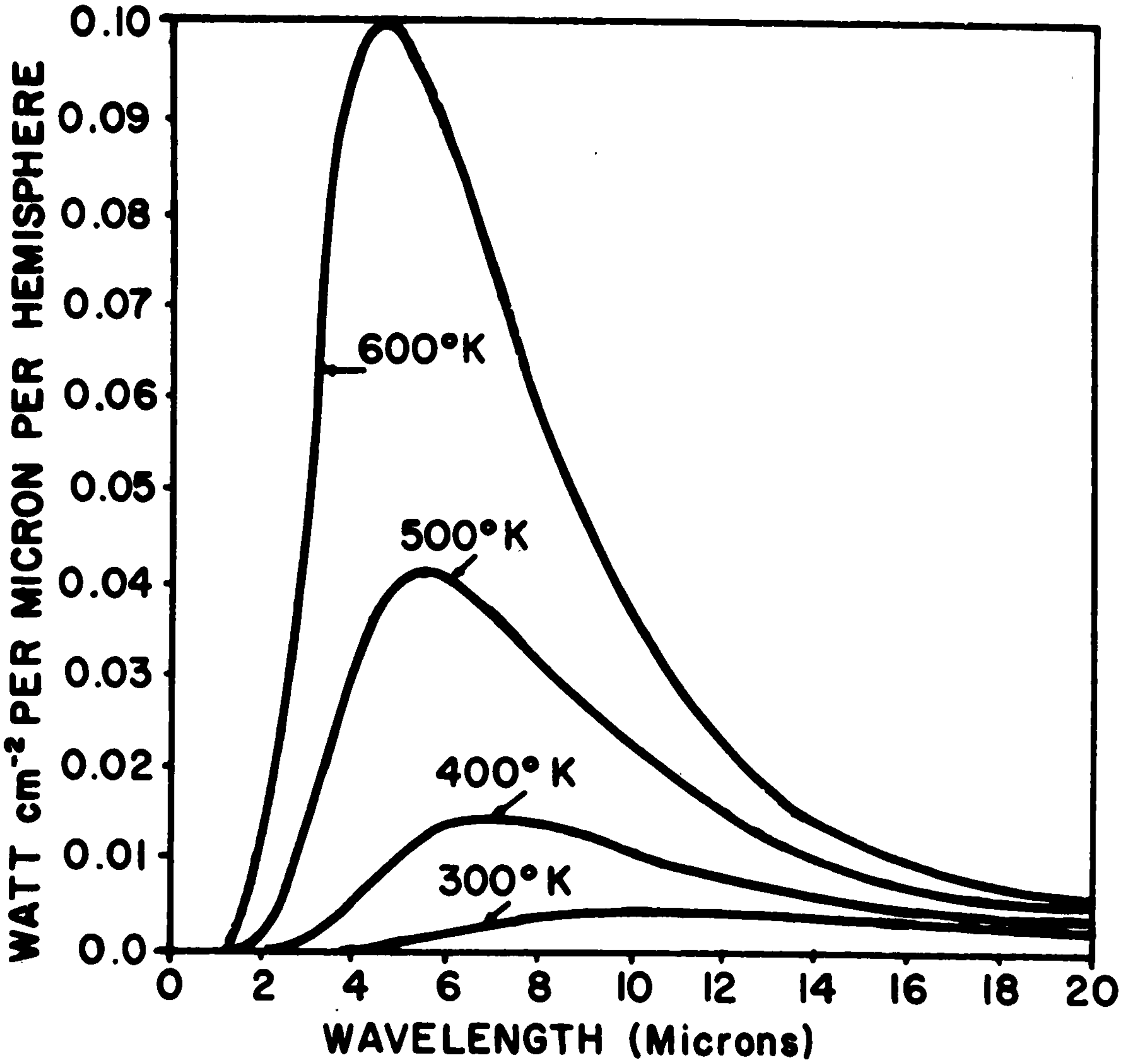

FIGURE 2 **Spectral Energy Distribution as function of Temperature**

nominal temperature for a terrestrial object, we see that the power falls off rapidly from a peak at 9.6 μ toward the visible region and asymptotically toward the microwave and radar frequencies. Self-emission at the two extremeties of the power spectrum even from a perfect radiator of ambient temperature is low and at the visible end is for all practical purposes non-existent. In nature, objects are not perfect radiators throughout the entire spectrum and, therefore, will reflect or transmit as well as absorb some portion of incident radiation. Consequently, we can make use of the property of reflectivity rather than emissivity. An active system can be used and reflected radiation can be detected and measured. At the radar end of the spectrum, we can transmit radar energy of different frequencies and measure the reflected component. At the visible end we can use solar radiation as the illuminating source and measure the reflected component. We can get some idea of the large amount of radiant solar power reflected in this portion of the spectrum by comparing the reflected solar radiation from an object with a ten percent reflectivity to that of the emitted radiation from an object of 300°K (Figure 3).

From the above discussion, it can be seen that if we know the values of reflectivity and emissivity of different objects within the different spectral regions, we can make predictions as to the appearance of these objects on a display of detected radiation. Insofar as we know the spectral characteristics of the object which we wish to measure, we may pick the remote sensing device that will give us the greatest discrimination. To be more sophisticated, we might wish to use an integrated system that would allow us to acquire pictorial data over a wide range of the electromagnetic spectrum. Such a system could feasibly include black and white film utilizing different filters, color film, infrared sensitive film for very near infrared reflectivity, infrared imaging devices equipped with different detector-filter combinations to furnish data in different regions of the infrared

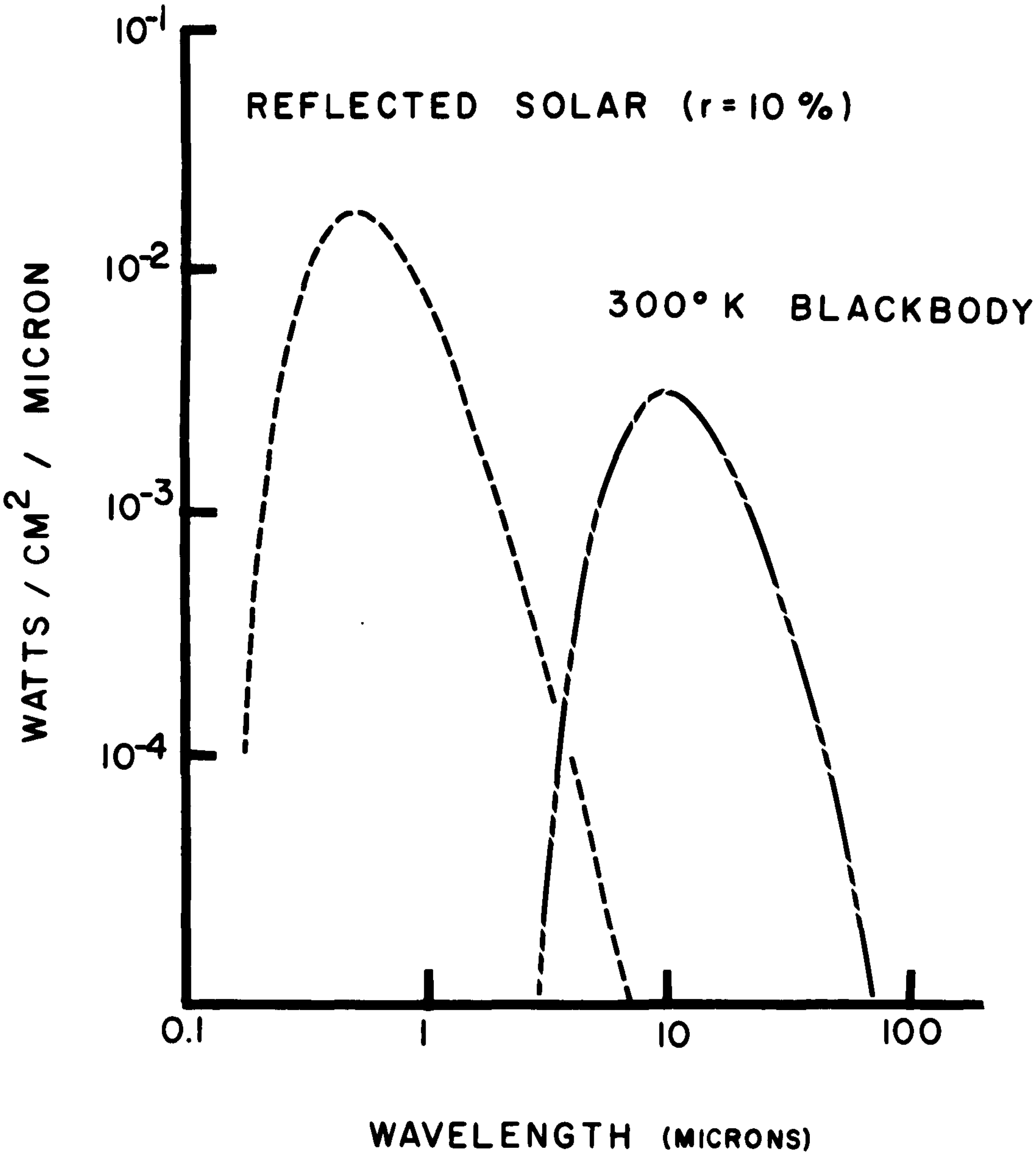
REFLECTED SOLAR (r = 10 %)
300° K BLACKBODY
WATTS / CM² / MICRON
10⁻¹
10⁻²
10⁻³
10⁻⁴
0.1
1
10
100
WAVELENGTH (MICRONS)

FIGURE 3

spectrum, a passive microwave radiometer to map emitted energy in the microwave region, and different active radars to measure the radar reflectivity of different objects at radar frequencies. This system along with some devices for measuring absolute brightness at the different frequencies could provide a maximum amount of data relative to type of object and its physical state, chemical makeup, relative or absolute radiation characteristics, etc. All of these data would contribute to the overall knowledge of a small or large area of the earth depending upon the magnitude of the study.

So far it appears that we have a very workable system and in theory this is true. In practice, however, when we look around for spectral analysis work conducted in situ on natural occurring features, i.e., soils, rocks, and vegetation, we find that such data are quite limited. One of the fundamental research problems that has to be solved prior to the ultimate utilization of remote radiation sensors is the determination of the spectral characteristics of terrestrial materials both in their natural state and also when refined into the basic materials used in our culture. This project needs to cover the complete spectrum from ultraviolet to radio frequencies. The problem is even more complex than it may seem at first since the influence of a changing meteorological environment on the terrestrial surface features should be investigated concurrently. Most of this work will involve in situ measurements and will have to be accomplished under the extremes of climatic conditions to be complete.

Measurement programs have been conducted in the past to determine some of the radiation properties of natural and cultural features. These have been for the most part piecemeal research projects conducted at different times by scientists in different countries for different purposes. In many cases different measurement techniques have been employed with the result that non-uniform data exist. Many of these data, however, are

quite valuable and are worthy of attention. A good example of a comprehensive in situ spectral reflectivity measurement program in the visible and very near infrared is that by the Russian scientist, E. L. Krinov. This work contains the results of spectral reflectance measurements taken on 370 natural and man-made objects in the region 400-900 millimicrons. It also is an informative narration on the trials and tribulations of accomplishing these reflectivity measurements and all of the years of work involved. This is just one such piece of research. The records of the American Society of Photogrammetry also contain reports by various workers on the visible and near infrared spectral reflectivities of different materials in both their natural environs and in the laboratory.

Published works on the spectral reflectivity characteristics of natural and man-made objects at wavelengths longer than 1 μ are more rare. This is partially the result of the relatively recent interest in the utilization of these electromagnetic radiation frequencies for remote sensors. A lack of awareness of the value of ground measurements of the physical properties of different objects may have further slowed research in this area. In any event, information concerning the electromagnetic radiation properties of natural and man-made objects at wavelengths greater than 1 μ is quite meager. Some programs of measurements of infrared emissivity and reflectivity values of terrain features have been conducted and reports on results are available. In many cases, however, these are laboratory and not in situ measurements. Comparable works on the electromagnetic properties of materials at the radar frequencies have also been accomplished, but here again published data are not abundant and not all pertinent parameters are treated.

Now that we have looked at some of the complexities involved at the radiating surface, let us next look at some of the problems involved in getting the radiation from the source to the detecting device. Since in order to do remote sensing of the terrestrial

environment, we must always interpose some finite atmospheric path between detector and source; we must consider what effect this atmosphere has on our incoming radiation.

In addition to the overall inverse square law attenuation due to the distance between source and detector, there are losses caused by constituents in the atmosphere that scatter and/or reflect and absorb radiation. These constituents are gases, smoke and dust particles, water vapor, and water droplets. If we look at a graph of the transparency of the atmosphere plotted against wavelength, we see that the atmosphere is not transparent to all wavelengths along the electromagnetic spectrum. In fact, at certain wavelengths, we see that the atmosphere is almost completely opaque.

The amount of atmospheric absorption and scattering is a function of pathlength, the amount of scattering and absorbing constituent within this pathlength, and the wavelength-particle size relationship. In the case of sensors mounted in low flying aircraft, the effects of the atmospheric constituents may not be as great as in the case of sensors mounted in satellites which detect radiation that has traveled through the entire atmospheric column.

In the ultraviolet portion of the electromagnetic spectrum, nitrogen and oxygen absorb radiation in the region .03 - .13 μ; and oxygen absorption in the region from .13 - .22 μ is nearly complete. Ozone acts to create an opaque region from 0.22 - 0.3 μ. Two oxygen absorption bands occur at 1.06 μ and 1.27 μ in the infrared portion of the spectrum. Many absorption bands of water vapor and carbon dioxide along with nitrous oxide, methane and ozone occur in the 1 - 24 μ region (Figure 4) and these make many areas within this region completely opaque to infrared radiation. Absorption by atmospheric water vapor virtually closes the atmosphere from 25 - 1000 μ. In the millimeter region oxygen absorption lines occur at 2.5 and 5.0 mm. In the microwave region a water vapor absorption line is found at 1.35 cm. Despite the large amount of absorption by the atmosphere

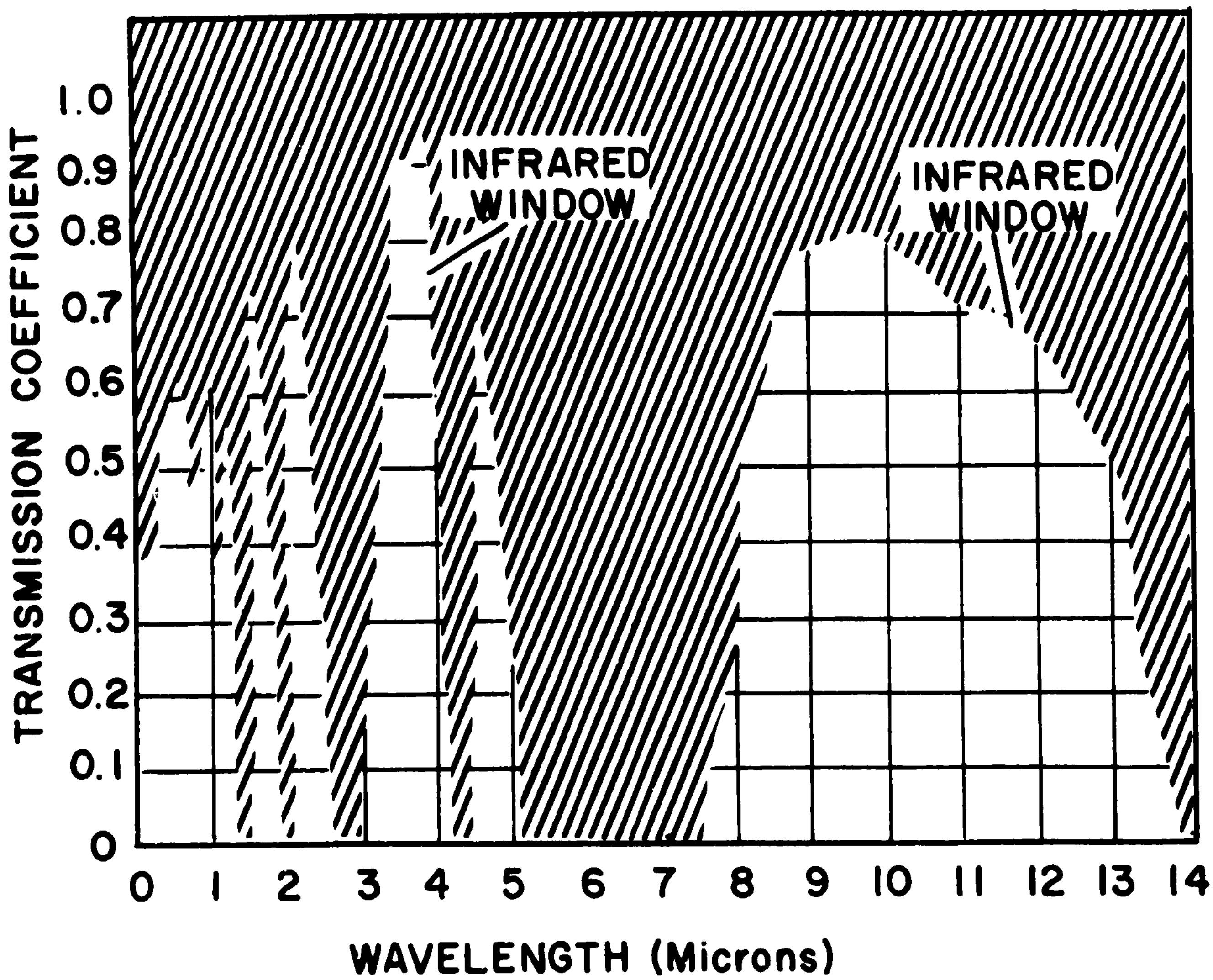

FIGURE 4 **Transmission Spectra of Atmosphere**

at different wavelengths, there are still many "windows" in the atmosphere which pass a large percentage of the total energy emitted or reflected at the wavelengths in which these windows occur. The optimum spectral region for obtaining a certain set of data is in part determined by atmospheric transparency to the propagation of radiation. Thus, it is a problem for the data analyst to consider and the instrument designer to be aware of. On the part of the data analyst it involves consideration of proper detector and filter combinations to limit the equipment to sensing radiation in the window area and thus reducing atmospheric noise caused by re-emission of absorbed radiation. On the part of the design engineer and scientist it involves a continuous search for improved detectors and filters to provide the capability of sensing in discreet spectral regions within the atmospheric windows only, if so desired.

Aside from atmospheric absorption and re-emission there is also the problem of scattering and reflection of radiation by particles, water droplets, and clouds within the atmosphere. Atmospheric particles scatter radiation as the inverse fourth power of the wavelength in accordance with Rayleigh's law. Consequently, particles of haze size (approximately 0.25 μ) greatly scatter radiation of ultraviolet and blue-violet frequencies. This scattering decreases toward the longer wavelengths in the visible portion of the spectrum. Likewise fog particles of approximately 4 μ radius will completely attenuate by scattering radiation in the near and much of the intermediate infrared. Clouds, with their relatively large areal extent and thickness, offer a complete shield between source and detector to those radiations in the visible and infrared regions. Radiation originating at the earth surface will be completely absorbed or reflected by the cloud. Radiation of most frequencies within the microwave and radar regions will penetrate clouds even if they are of great thickness.

From the above discussion of the objects to be studied and the nature of the transmitting medium, we can immediately begin to write down limitations and capabilities of electromagnetic radiation sensors to remote sensing applications. Starting at the short wavelength end we see that at the ultraviolet and blue-violet end of the visible spectrum, atmospheric scattering of radiation is so nearly complete that these frequencies are of little value for sampling terrestrial objects. These frequencies should be kept in mind for possible extra-terrestrial applications. The remainder of the visible spectrum may be used or certain portions may be sampled separately by utilizing appropriate filters. The very near infrared (out to about 1 μ) may also be sampled using photographic techniques, infrared sensitive film, and appropriate filter. Sensing devices operating in the 0.5 - 1.0 μ region have many advantages for recording terrestrial phenomena and certain atmospheric phenomena. Because of the nature of the radiation and the means of recording it, the resolution of object detail is very high. The presentation is in the form of a display for which a scale value can be computed and consequently measurements in x-y dimensions can be made. Also in passing, the three dimensional stereoscopic effect of the overlapping photographic imagery is another inherent attribute of utilizing this wavelength region. Because we are recording the familiar features which we sense with our own eyes, we also find that deductive analysis of aerial photography may be quite straightforward in some respects. The limitation which we find to be most stringent upon visual and near infrared photography used for sensing of the surface of the earth and atmospheric phenomena is its limitation to use in areas illuminated by the sun.

Utilization of the infrared wavelengths for remote sensing of the earth surface is limited to the atmospheric window regions. Fortunately, one large atmospheric window area occurs in the 8 - 14 μ region and coincides with the peak of the radiant power curve

for ambient temperature objects. Utilization of the infrared region for atmospheric research may make use of the entire infrared spectrum for net radiation measurements, etc. Because of the nature of the radiation and the method of recording, infrared maplike presentations are of a lower resolution than are records made in the visible portion of the spectrum. Because the systems employed sample emitted radiation from terrestrial objects, there is no diurnal or seasonal restriction upon their operation. Consequently, thermal measurements in the Polar regions can be conducted during the winter season and atmospheric radiation studies of cloud surfaces or net radiation may be conducted during both day and night. This is also true of the passive microwave systems although there is an even further reduction of resolution on the maplike display. Passive microwave devices, however, have a better all weather capability for mapping terrestrial objects, as have the active radar systems. The active radars like the passive microwave also have a relatively low resolution capability compared to the photographic and infrared display.

These are but a few of the more apparent limitations and capabilities of the electromagnetic sensors. A more comprehensive list will be developed during subsequent lectures dealing with the specific sensing systems.

Before leaving the electromagnetic sensors, it may be well to mention the type of readout that we will get from the different systems. The detected radiation may be displayed in various ways. In absolute measurements it may be displayed as a chart recording of radiation levels from discreet areas underneath the remote sensing vehicle. In relative measurements, it will usually be displayed as a maplike presentation of finite areal extent. Here again this will be discussed in detail later.

The second category of remote sensors are those that measure some component of force or total force at a point in space. These include the sensors that measure

gravitational forces and magnetic field forces. These sensors may be used to great advantage in helping to solve problems relating to the true size and shape of the earth, earth and planetary gravity and magnetic fields, unification of the geodetic and gravity datum of the earth, etc. They may also facilitate tracing of large scale regional magnetic and gravity anomalies which are indicative of subsurface earth structure. The increased knowledge of earth gravity will promote the state-of-the-art of programming flight trajectories for ballistic missiles and earth satellites. It will also extend the current knowledge of earth gravity and magnetics into the polar regions.

One of the most severe limitations on the force sensors is that the detectable force decreases as the inverse square of the distance between the disturbing element and the detector. Thus, small scale gravity or magnetic anomalies that are of interest to the economic geologist will be lost on any except very low altitude flights. The sensitivity of airborne gravity detectors is also limited by accelerations acting on the carrying vehicle. Other limitations and capabilities of these force detectors will be discussed during the presentation by Dr. DeNoyer.

In summary it should be stressed that the remote sensors are not a cure-all for all earth science problems. Each has certain physical limitations. Some of these limitations are inherent in the nature of the quantity being sensed and no amount of refinement of instrumentation or technique could change this situation. Others are state-of-the-art limitations which may be overcome through advances in the technology of instrumenting and measuring. Regardless of the limitations of the sensors that we have to work with and the fact that some limitations are unresolvable, there is enough potential and practical capability inherent in state-of-the-art equipment that earth scientists should seek to acquaint themselves with these capabilities. It is through a special cognizance of the capabilities

inherent in remote sensing that potential applications will be conceived, tested and if proven feasible, help to add to our overall knowledge of our environment.

AIRBORNE GEOPHYSICAL DEVICES; STATE OF THE ART AND APPLICATIONS

John DeNoyer

Airborne measurements that are used in geophysical investigations are of several types. Some of the most important of these measurements are:

Aeromagnetic - measures total magnetic field.

Radiation - scintillation counters.

Electromagnetic - measures conductivity near the surface, shallow penetration, low altitude.

Gravity - experimental to operational.

Aeromagnetic methods are by far of greatest importance at the present time. Airborne magnetic instruments can be built that have very desirable sensitivity characteristics for both geophysical and military applications.

Airborne magnetometers in use today are of two general types. The most common type is the flux gate which utilizes some basic principles of saturable core transformers. The second type, which is rapidly gaining in popularity, is the proton precession magnetometer. Each of these instruments will be discussed briefly below.

Figure 1 shows a rough schematic diagram of the detecting element of the flux gate magnetometer. This detector consists of two saturable core solenoids. The solenoids are alligned in the same direction but are wound with reversed polarity. This is a symmetrical system in the absence of an external magnetic field so the current flowing to the servo mechanism will be zero. In the presence of an external field, H_e, the sum of i_1 and i_2 will not be zero since H_e is helping to magnetize one of the cores in the same direction as the coil and tending to retard magnetization of the other core. This current controls a servo motor that adjusts rheostat, R, until the nulling coil cancels the field H_e. The nulling coil constant is known and the current flowing through the nulling coil is easily measured. The strength of the nulling field can then be readily obtained. The nulling field is equal and opposite to the field of the earth, H_e, so that we have a measure of the earth's field.

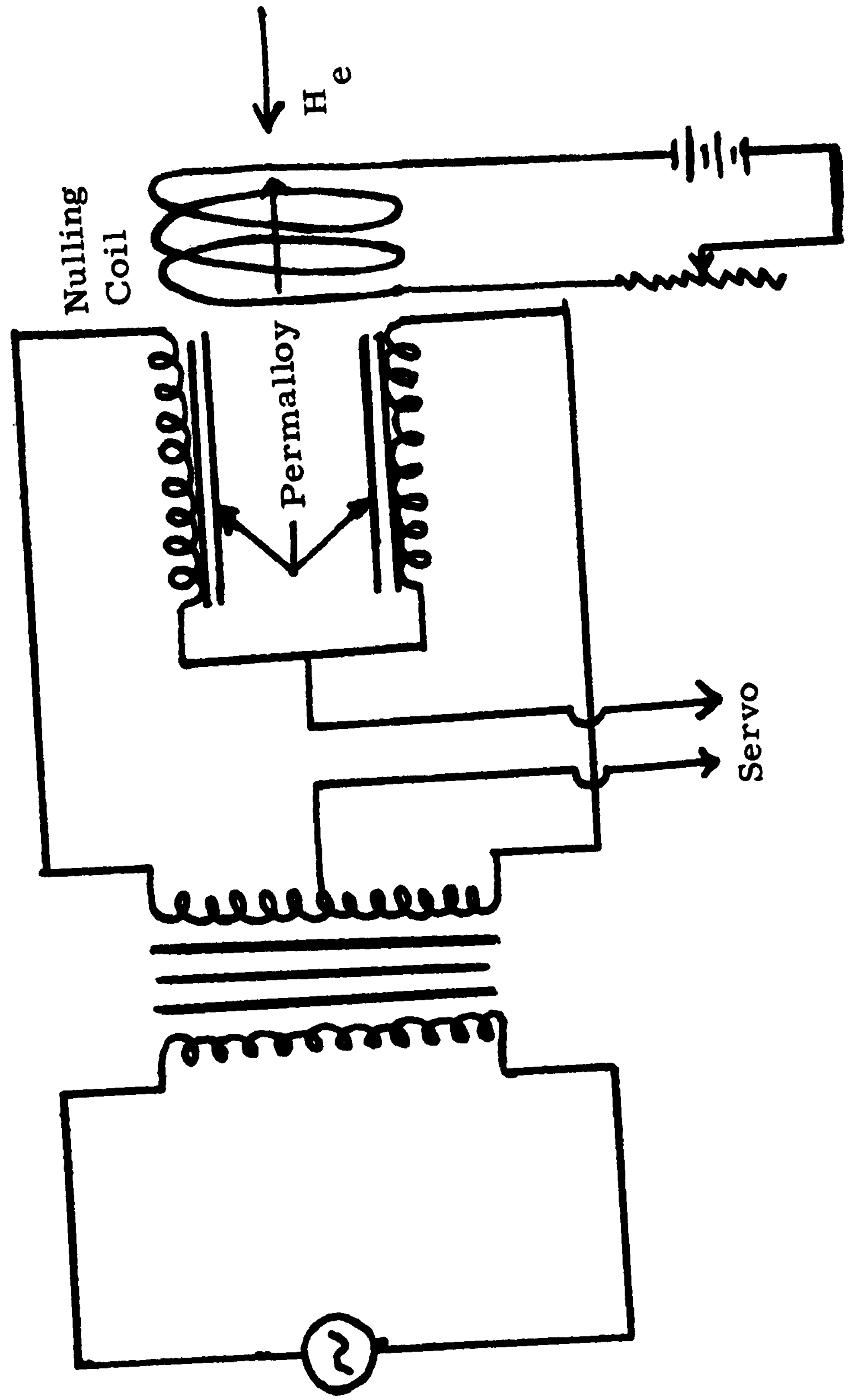

FIGURE 1

For most applications, two additional flux gates are used to control servo motors that keep the detecting head alligned in the direction of the total field. Many modifications of this basic scheme have been used. The sensitivity of such devices is often in the range of 0.25 gamma. One gamma is 10^{-5} oersted.

Some difficulties in operation of this type of equipment come from isolation of the detector from magnetic fields of the airplane. If the detector is mounted back of the tail assembly or on the wing tip, very elaborate care must be taken to balance out all permanent fields due to the plane and also to effectively balance out eddy current fields resulting from the conducting skin of the plane passing through the earth's magnetic field. In some cases the detecting head is towed about 100 feet behind the aircraft in a separate package called a "bird".

The proton precession magnetometer utilizes the period of precession of proton dipoles about magnetic lines of flux. First the protons are alligned in some direction other than that of the field of the earth by an energizing coil. After the energizing field is removed, the individual proton dipoles begin to return to their orientation with respect to the field of the earth. As they return to this position they precess about the lines of force from the earth's magnetic field with a frequency that is proportional to the strength of the earth's field. The same coil used to energize the protons now serves as a detecting coil. Each proton dipole precesses with the same frequency so the alternating emf induced in the coil adds to a detectable signal. All that is needed now is to measure the frequency of precession to obtain the strength of the earth's magnetic field.

This instrument does not need accurate orientation and the various portions of the equipment can be made very compact. Commercial models are on the market for land, sea, and airborne use. Special models have been built for use in satellites. Readouts can be direct reading or recording in either analogue or digital form. The sensitivity of these instruments depends on the selectivity of the frequency measuring device. One to ten gammas are commonly quoted sensitivity values for ground based instruments. Airborne instruments are built with a sensitivity of about 0.25 gamma. Some satellite magnetometers have sensitivities of very small fractions of a gamma.

The first successful airborne gravity survey was made in November of 1958. Instruments used for this type of measurement are necessarily devices that balance a mass with some restoring force. Any accelerations in the direction of measurement are indistinguishable from the gravitational acceleration. Gravity meters are very sensitive to tilt as well as the usual vertical accelerations they are designed to measure. These conditions require that the gravity meter be operated on a stabilized platform to prevent tilting. Vertical accelerations of the aircraft must be kept at a minimum and averaged over several oscillations. The direction of flight must be maintained throughout the traverse. Elevations above sea level must also be known.

The accuracy of airborne gravity surveys at the present time is about $\pm$ 10 milligals. The milligal is 10^{-3} gal (1 cm/sec^2) or about 10^{-6} gravity. This requires that vertical accelerations of the aircraft should not greatly exceed 10^{-5} gravity even though an averaging process is used. The elevation of the aircraft above sea level must be known to within 100 feet. The centrifugal acceleration that arises from the aircraft moving around the earth changes the observed vertical component of acceleration from what would be measured if the observation point had been fixed on the surface of the earth. As a simple example let us consider a plane flying in a west to east direction at the equator with a ground speed of 1000 km/hr. The total Eötvös correction will be about 2060 mgal and will be changing at a rate of about 2 mgal per km/hr. To obtain a correction accurate to within 10 mgal we will have to know the ground speed to within 5 km/hr. Additional complications arise from flights with north-south components in the traverse. The difficulties that arise in airborne gravity surveys can and are being overcome at the present time. The restrictions may never let us make as detailed gravity studies from aircraft as are possible for the magnetic field with airborne magnetometers. The airborne gravity meter does, however, offer great promise as a reconnaissance tool and a rapid method of mapping the gravity field over large portions of the earth.

To complete this discussion, let us consider the relative magnitudes of the quantities we are concerned with.

	Magentic	Gravity
Earth's Field	0.25-0.7 oersted	978-983 gal
Unit of geophysical measurement	gamma = 10^{-5} oersted	mgal = 10^{-3} gal $\approx 10^{-6}$ g
Noise	Storms: up to 1500 γ Diurnal: about 20 γ	Diurnal: 0.24 mgal
Magnitude of anomalies (observed - Computed)	Up to several thousand gammas	10 to a few hundred mgal for airborne work. 0.01 to a few hundred mgal for surface work.
Relative sensitivity: ground/airborne	1	1000

In general magnetic anomalies amount to a much larger fraction of the earth's total magnetic field than do gravity anomalies of the earth's total gravity field. Instrumentation for aeromagnetic surveys provides as much sensitivity as can be used in most applications. This is largely the result of the ease with which non-inertial magnetometer sensors can be built. The gravity field is much more difficult to measure with airborne devices. The instruments are a factor of 1000 less sensitive than their groundbased counterparts. Even with this low sensitivity, the airborne gravity meter offers promise for investigating large gravity anomalies in short periods of time. It also makes it possible to map the gravity field of the earth over otherwise inaccessible areas.

DISCUSSION

Dr. Suits: I'd like to get some intuitive feeling for the numbers that you have used to describe the sensitivity of measurement.

John DeNoyer: Well, a good gravity meter will certainly record most of what we call microseisms. You can watch it and see it oscillating. These are oscillations of maybe a few millimicrons at one cycle per second, and the meter will follow these oscillations quite nicely. These are incredibly small quantities. I don't think most of us feel an acceleration of one g in starting our car, I know mine won't accelerate that fast. We have been discussing one hundredth of a

milligal. This is working to the order of 10^{-8} g. The total magnetic field of the earth ranges from about 0.25 to 0.7 oersted and the common unit that we use is one gamma which 10^{-5} oersteds or roughly 10^{-5} of the total magnetic field. These are small quantities.

Dr. Suits: This means then that if you approach one of those devices with an iron belt buckle or something you might be in trouble.

John DeNoyer: I had an amusing experience with that with an assistant a couple summers ago. He couldn't understand why he couldn't get consistent readings on the magnetometer. He had stripped himself of everything. He was an electrical engineer too, and a camera fan. He carried a light meter with him. Every time he approached the magnetometer, it went off scale. The tacks in a persons shoes would have an effect on a magnetometer several feet above the ground.

Dr. Suits: Both the gravitometer and the magnetic sensing device are not troubled with internal equipment noise but only the external things, is that correct?

John DeNoyer: They are troubled with internal equipment noise, such as drift in a gravity meter. It can be troubled by barometric changes, and compensation of some kind has to be put in for any of these things referred to as internal trouble. They can build them with very satisfactory characteristics. One common gravity meter is put inside of a hermetically sealed unit inside a thermos bottle to lag changes and then there is thermal compensation built into it also.

Question: You talk about the milligal with respect to both the gravity meter and the magnetometer.

John DeNoyer: No, the milligal is a unit of gravity; the gamma is the unit of the magnetic nature.

Question: If the question is applicable, what is the field of view that these magnetometers see as related to a force in the ground of an airborne magnetometer?

John DeNoyer: How would the field vary between an airborne survey and a ground survey; is that the question?

Question: How accurately can you pinpoint the disturbance in the magnetic field?

John DeNoyer: [The answer involves a blackboard sketch]

Dr. Suits: How far beneath the surface would you find the object causing the anomaly?

John DeNoyer: The configuration of the magnetic anomaly depends upon, not only the space, but the direction of magnetization. You can find the location quite precisely. It has to be a fairly large body to give you anything on the air-borne survey. You can get pretty well in the vicinity of it. You can also make some pretty good estimates of the depth of this body from the period of the variation.

Bob Frost: How do you arrive at the height that you fly?

John DeNoyer: If we know a force field over an entire surface, we can then calculate what it would be at any other surface; this is known as "a downward continuation". Usually we are interested in going down instead of up, and it doesn't really make any difference what height you fly at as long as the effect is strong enough to be recorded. You can continue it down to any level you want to.

Morris Weiss: Could you give us some principles of one magnetometer and gravity meter?

John DeNoyer: Most of them are a mass which is supported by some restoring force mechanism. The sensitive ones are such that the greater the mass is deflected from its equilibrium position, the less will be the restoring force. This can be done by having a lever arm that changes effectively in length as you displace the mass from its rest position. When the mass is at rest the lever arm is longest for the restoring spring and when it is deflected some, it becomes shorter. As far as principle goes, we could make a very simple one by hanging a mass on the end of a spring and disturbing its rest position. This wouldn't measure anything to one hundredth of a milligal. Most of them are made with maybe a mass on the end of a boom and an arm to which is attached the supporting spring, and some mechanisms for nulling the instrument to its original zero position.

Morris Weiss: Is gravity always directed toward the center of the earth?

John DeNoyer: Well, we have to make our measurements, as a rule, in the direction of the total gravity field, because this is what we design as level.

We could do it in a direction towards the center of the earth if we make an astronomical observation at each location. Down isn't toward the center of the earth for most of the earth.

Morris Weiss: Is there any damping fluid on this?

John DeNoyer: Yes, there is.

Dr. Suits: The temperature, I imagine, is important.

John DeNoyer: The temperature and the exact geometry of this mechanism are important. The Worden gravity meter which is very popular has the full mechanism made up of quartz, which is then put into a little watch box size unit and then put into a thermos bottle and sealed.

Yale Katz: What is the time sensitivity of the gravity meter, or the free period?

John DeNoyer: This varies somewhat according to the use. A lot of the meters have a period of between two and six seconds. Some of the other meters have periods up to twenty seconds and longer. A lot of the very sensitive meters have periods up to twenty seconds.

Yale Katz: Is the gravity meter a possible device for indicating aircraft stability?

John DeNoyer: Most of them are way too sensitive. They are also sensitive to tilt as well as vertical acceleration. Much less elaborate devices serve quite well for this.

Robert Frost: Can you fly a gravity meter and a magnetometer at the same altitude? Is there an optimum altitude?

John DeNoyer: Magnetometers are usually flown at lower altitudes than gravity meters. This is because we can afford to get down into turbulent air. The magnetometer is non-inertial, you can bounce it up and down and it won't be disturbed, but the gravity meter is restricted to air which is non-turbulent. Gravity surveys are usually flown no lower than 20,000 feet and preferably up around 30,000 feet, while magnetic surveys can be flown at any altitude you want to fly.

Question: Is it true that a gravity meter or a magnetometer has a field of view that is related to height?

John DeNoyer: The pracitical field of view, yes, but the whole earth affects any gravity device and all magnetic materials in the earth have a very small effect on any magnetic devices so it all depends on how sensitive your instrument is and whether you can separate this effect out from the rest of the perturbations.

Mike Holter: In the sense of telescopes though the gravity meter has no field of view. The gravity meter measures field intensity at a point. Things in any direction from that point can affect it.

John DeNoyer: If we are flying over a portion of the surface of the earth there is a region which will contribute most. Now this all depends on what you consider to be the most. The moon way off somewhere is also contributing. You have a complete enclosed solid angle of effect.

Question: How high could you fly and see an automobile on sedimentary rock magnetically?

John DeNoyer: Probably about 300 feet.

Comment: Looks like it would be pretty hard over mountainous country to explore at 300 feet.

John DeNoyer: Well, you aren't looking for cars you know. You are looking for something like the Mesabi Range.

RADAR TECHNOLOGY AND REMOTE SENSING

Newbern Smith

Normally when we look at an object, we see either the radiation which is reflected from the object or radiation which is emitted by the object. Detecting the radiation which is reflected by the object from an illuminator like the sun, for example, is what I mean by semi-active sensing. The object is illuminated from somewhere and we see it in reflected light. Radiation which is emitted by the object I call passive sensing since the object will emit radiation as a result of physical state without any external source of radiation. Now to delimit the topic a little bit, I'm not going to talk about passive sensing today. You will hear about that tomorrow morning when Dr. Vivian gives a talk on passive microwave methods of detecting and exploring the environment. I'm going to talk most about active sensing in which we have at our control the means of illumination. We don't rely on an illuminator like the sun, but we ourselves furnish the energy which illuminates the environment which we are trying to describe. In this manner also, we can make use of coherent radiation; that is, radiation which is coherent from one cycle to the next. It is possible to describe the form of radiation which we are emitting and to compare the radiation which is reflected with the radiation emitted; and thereby, find out what modifications have been introduced by the environment. Also, I'd like to say a few words about the breadth of the spectrum. Radar in the conventional sense is a high frequency job. Frequencies below about four or five hundred kilocycles are not used for radar in the conventional sense; and frequencies very much above about ten or fifteen thousand megacycles are not used for a different reason--namely that they don't go anywhere. They are absorbed by the atmosphere. Below four hundred megacycles, however, there is a large spectrum

percentagewise. There are a lot of octanes below four hundred megacycles, and these can predict information in the same way that the spectrum above four hundred megacycles can. The only thing is, you have to do it somewhat differently than in the conventional pulsed radar.

If we have a radio wave, there are different ways in which information can be carried by that wave. This information exists in the form of the amplitude, the phase, and the state of polarization of the wave whether it is vertically or horizontally polarized or elliptically polarized together with variations of these qualities with time and position. Any physical object in an electromagnetic field disturbs the field and imposes on it changes related to the physical nature of the object. If there is a large object in a field, you will see the effect of its presence by means of a reflected wave, a wave that is scattered or reflected. The effect of such a scattering depends on the physical nature, size, and shape of the object; and the aspect of it; and the relationship of all of these to the wavelengths of the radiation which you are using. These effects appear remotely and form the basis of remote sensing by radio means. So we can generate an electromagnetic field of known characteristics such as a pulsed wave in the radar sense, or a coherent continuous wave of which we know the amplitude and the phase; and by exploring certain aspects of the field, learn remotely much about anything that is in the field that has enough of an effect. In classical radar, what we do is to compare a transmittal wave with a wave that is scattered or reflected from an object. Originally, radar was invented for the purpose of simply detecting whether there was an object there or not in a place where normally there would be none--namely, the air. In this matter, then, what they did was to generate a pulse signal and compare the received signal with the pulse that they sent out. The comparison was crudely done in the beginning and was simply a matter of the relative amplitude and the relative time.

There was very little in the way of resolution, because there were no sharp beams; and it wasn't until the use of higher frequencies and more sophisticated techniques produced sharp radar beams that one could begin to measure anything except the presence of an object and its distance.

Let's think about what characteristics of the environment affect a radio wave or the physics of scattering or reflection of a radio wave from an object. Basically, it is simply this: when an electromagnetic field hits any medium, any dielectric substance or conducting substance, it produces a motion of the electrons in that substance. These electrons move according to the prescribed laws of Maxwell; and in so doing, reradiate the energy which they have absorbed. They reradiate in a different phase and with a certain amplitude, and we can describe an object as having a reflection coefficient with a certain amplitude and a certain phase shift such that if we were to compare the reflected signal with the signal which is transmitted, we could determine the reflection coefficient and thereby the electrical characteristics. It would thus appear very practicable to measure reflection coefficients and determine therefrom what the dielectric constants and conductivities are; and of all the various substances that one might expect to be present, one might be able to identify objects which actually were there. This holds regardless of whether we are talking about continuous wave radiation or pulsed radiation. The use of continuous wave is also called radar although it departs from the original meaning of the term. One can obtain information on the reflection coefficient, distance, and state of motion of an object just about as well by using CW techniques as by using pulse techniques; provided again that you make use of some ingenuity in the manner in which you do these things. Pulsed radar as indicated occupies mostly very high frequencies. Part of this lies in the desire to have resolution in azimuth and in distance. Resolution in distance involves

using very short pulses. Resolution in azimuth is achieved by using narrow beams. A narrow beam can only be achieved by having a high ratio of aperature of the antenna to the wavelength. The beam width of an antenna, in fact, is of the same order of magnitude as the wavelength divided by the aperature. That is the beam width in radians. At low frequencies, it is very hard to get antennas which are many wavelengths across. Certainly, they are not the sort of thing that you can lug around easily or put in an airplane. Consequently, we are lacking in resolution at the lower frequencies; and because there too you can't get sharp focus, the pulsed radar methods of operation are not particularly applied.

The two principal ways in which one might consider using electromagnetic sensing would be from a fixed location or a series of locations on the ground or from the air, and one should consider the relative merits of the two kinds of operations. If you have a ground installation, the only thing you can do is to measure the characteristics of waves reflected from objects within the line of sight of the radar. Now this may not be particularly useful because if the thing is in line of sight, it is often better just to go up and see what it is rather than depending on an indication which is complex. This does not add very much, in other words, to our total technique and the conclusion might be reached that airborne radar or radio means would be the most fruitful way of applying this technique to remote sensing.

What can we find out now? Given sufficient resolution, we can find out shapes of objects; we can find out the characteristics of reflection which depend upon shape and on composition. We can do something else too; we can make use of the fact that radio waves are not reflected strictly from the surface of every object, but they do penetrate to some extent into the object and we get a sort of a composite reflection coefficient which is averaged over the depth to which these waves penetrate. At very high frequencies they

don't penetrate very far; most reflections come from the surface. At low frequencies, though, the penetration gets considerably greater. By low frequencies I'm thinking of one megacycle or lower, a few hundred kilocycles. These frequencies do penetrate the ground for quite a bit. As a little aside, I might mention that this property was made use of many years ago when the question came as to allocation of frequencies for broadcasting stations. The allocation of frequencies depends upon the distance to which the broadcasting station can transmit; and this depends on the conductivity and dielectric constant of the ground, not of the surface of the ground, but of the ground as far down as these waves will penetrate. The FCC made a survey of the country in terms of the average ground constant and turned up with a very nice map which some of you may have seen or may be familiar with. I don't know if the interpretation of this map has ever been undertaken in full, but the correlations with soil type and the discrepancies that arise when you try to correlate it with just the surface ground certainly would give an indication as to the nature of the subsurface layers.

Now, what else happens when a radar pulse is reflected from an object? The process of reflection takes place; also a process of reradiation, which I described as producing a reflected wave, is really a scattering. Radiation is scattered in all directions; and if the object is such as to produce a sizeable amount of coherent radiation coming back at you, we call it a specular reflection. The scattering goes off at all angles. We describe an object, then, by what we call the radar cross-section. Perhaps I should say a few words about radar cross-section. Radar cross-section, for those of you who don't know, comes about in this manner. Suppose you have a certain power radiated from the antenna, P_c. If this were radiated through all space, at a distance R, the power density would be

$$\frac{P_c}{4\pi R^2},$$

but it isn't radiated uniformly throughout all space because we have a beam forming antenna. An antenna confines the radiation and channels the power more in one direction than in another. So I'm going to say let g be the gain of the antenna, the amount by which the power density is greater in one direction than in another. This, then, is the power density in watts per square meter at a given distance R. Now, the total power scattered by an object at that distance is then given as

$$P_s = \frac{P_c}{4\pi R^2}\,\sigma,$$ where σ is the radar cross-section.

Now this is the power. We can't get away from considerations of polarization. We have to transmit a certain polarized radiation if we are to have it coherent. So it can be linearly polarized, circularly polarized, or elliptically polarized; but it has to be polarized in some manner or other. Consequently, the radiation coming back is going to be polarized also; but this might be polarized randomly. In other words, the sigma might be such that it produces a random series of components of polarization of the returned wave, or it might produce the components which have the same polarization, or components which have the conjugate polarization. It can in general produce a different polarization in the received wave. Sigma itself, which is defined with respect to power, can receive a more general definition in that it can also include the state of polarization of waves which are coming back. This is very important from the standpoint of distinguishing different kinds of substances. Different kinds of substances should be characterized by the state of the polarization of the wave which they reflect, as well as by the amplitude and phase shift which are characteristic of a homogeneous medium with a certain dielectric constant and conductivity. One other factor also deserves a great deal of consideration and this is the use of different frequencies in electromagnetic sensing. Again, for equipment purposes, most

radars operate on only one frequency, because it is too expensive to have radars operating on every frequency. However, you can gain a great deal of information by observing objects at different frequencies, because the characteristics of reflection and refraction or complex reflection coefficient differs with frequency. We can gain a lot of information this way by using different frequencies and comparing the two.

I want to mention, in passing, one of the primary uses of radar in describing the environment--namely, radar mapping. I am not going to say anything much about it because the speaker who follws me is going to say much more with a few very nice illustrations of this. I'll simply say this much: one of the unique properties of active radio radiation for sensing is that it possesses a distance measuring power. The comparison of phases gives us a very nice measure of distance, and we can use this distance measuring property in order to display the terrain in the form of a map. There will be no foreshortening such as there would be in looking at and taking an oblique photograph of a piece of terrain for example, or even taking a wide-angle view from directly overhead photographically. A map produced by this method, in other words, is rectified.

A brief word about earth science applications. Earth science leads one to ask, where does the earth end? At present, I would hate to say that it ends anywhere short of halfway between here and the moon. Certainly outer atmosphere shows the effect of the earth out to at least 18 - 20 earth radii. This is a special subject in itself and not too much is known about it. However, I would like to point out that pulsed radar has been in use for many years in exploring the earth's upper atmosphere and exploring the ionization density in the ionosphere beginning about 50 or 60 kilometers high and going up to the maximum of ionization density at about 300 kilometers above the surface of the earth. Above that, we didn't know very much until we had more powerful transmitters for

exploration, and also, incidentally, techniques utilizing rockets. But those of you who have had experience with the very variable phenomena that we get in geophysics, terrestrial magnetism, and so on, know that one datum is meaningless; and it isn't until you get specifically significant sampling over the whole range of radiation that you really begin to know something about it. So, the advent of more powerful radar equipment at lower frequencies enabled us to make use of the scattering problem of the electron itself. The electron has a radar cross-section of about 10^{-18} square meters. It takes a lot of electrons to produce an appreciable reflection, but there are a lot of electrons in the upper atmosphere; and it has proved possible to extend our knowledge of the atmosphere on a regular basis up to as high as 800 - 1000 kilometers by means of this technique. This is real remote sensing. At much lower frequencies than the normal radar frequencies, the reflections of radio waves from the ground have largely been unexploited as an indication as to what may lie below the surface of the earth. When we think of airborn observation, one thinks of an airplane, but I don't think one necessarily needs to think of an airplane in that respect. I would have in mind possibly some device such as a variable frequency transmitter mounted on a balloon which is hovering over somewhere; and then running up a sweep frequency receiver, and so getting a complete spectrum of the ground reflection sufficient to delineate the characteristics of the wave reflected from the ground. I don't know to what extent this would be practicable or improve our knowledge of the earth, but it seems to me that there are some possibilities. Within resolution limitations, ordinary conventional pulsed radar will give remote data on terrain features; it will give some data as to whether the terrain is rolling or not and would conceivably give some indication if you had good enough resolution of subsurface features which might affect the surface above them. If you had a whole family of moles drilling along the ground and raising it up, you might

be able to see that providing your radar had high enough resolution. We don't know of any radar today that would do this, but it might possibly be exploited. One of the chief things of importance is that the use of radio gives a different picture from that obtained by visual, photographic, infrared, or other means. It gives a different picture because we are using a different part of the spectrum. The reflection characteristics are different. The things which appear light in one part of the spectrum may appear dark in another part of the spectrum; and by using the wide variety of color difference which you can get in going from a few hundred kilocycles up to a few thousand megacycles, you may conceivably have a means for getting considerable information about the nature of the surface you are looking at. I'm not talking particularly about using this technique on a small passive surface, because small passive surfaces aren't resolved at low frequencies. You have to use high enough frequencies to limit the path to the thing you are looking at; but in exploring some large portions of the surface, you might well be able to make use of a technique like this. In order to do this, we would have to know more about the natural reflective properties of terrain and foliage. We would need to know more about the relations of these things to the physical nature of the terrain. We know, for example, that the reflection from trees is quite different in the winter than it is in the summer. This is largely because the main reflecting agent in the trees is water; and the main place that water accumulates is in the leaves in the summertime and in the wintertime it's dried out, and you just don't see very much then. I think also that along with the radio means of sensing, you would do well to include other sensors. Radio itself is a conjunction of several different kinds of sensing. It could be the pulse ranging type; it could be the continuous wave reflecting type, and all of these working together can give you a much better picture of what you are looking at than just one signal by itself.

I should mention one more thing, and that is that electromagnetic or radio reflection techniques are presently being used and being developed for the purpose of finding out what the surfaces of other planets are like--the thickness of the lunar dust on the moon for example. Measurements at the radio albedo at the moon have produced some very interesting data.

Gwynn Suits: I wonder if you know of any data concerning the characteristic reflection of the complex wave from uniform materials such as concrete and granite? Is there any spectral information of this nature on these common materials?

Newbern Smith: I think I have seen something like that; and if I recall rightly, it was a classified document.

Carl Molineux: Vicksburg is developing a four-band radar which works in C, K_a, X and C bands. They are running controlled samples with the intent of developing a catalog. It is unclassified.

Linn Hoover: The January 1962 issue of the Geological Review published by the American Geological Institute has a translation of a Russian article on low frequency radio waves in making subsurface geologic maps. It was an extensive article, more on application than on theoretical problems.

Question: How large must the field of view be?

Newbern Smith: I was thinking in terms of low frequency radar. The area has to be at least comparable with the wavelength.

Bob Moxham: Are you familiar with laser radar and its possibilities?

Newbern Smith: This is an interesting question on a subject that lies between radio and infrared. I think we can claim it for radio, because it is coherent. Most things which can be done with coherent radar at high frequencies can also be done with the laser.

DISCUSSION OF EXAMPLES OF RADAR IMAGERY

Wendell Blikken

[A clarification ruling on the talk presented by Mr. Wendell Blikken is being sought at this time. Consequently, the text is being retained and will be available to those people interested in obtaining a copy subsequent to a favorable ruling.]

PASSIVE MICROWAVE TECHNOLOGY AND REMOTE SENSING

Weston Vivian

The passive microwave business is sort of a half-breed, neither radar nor infrared. The physics is infrared physics; the instrumentation is generally radar equipment. The familiar version of this is radio astronomy.

Security wise I have some problems. Probably the best basis for my talk being unclassified is an article in Aviation Week some five years ago. I have copies here and will hand them out in a few moments. This is an unclassified release; it says a lot of things that I want to say and includes one graph that I will show a little bit later.

What are the reasons for even bothering with passive microwaves? First, all of you know that infrared devices have trouble with propagation in many varieties of weather. You are also aware that penetration into the ground or into natural surfaces is almost negligible. If you get down a few microns, it is most unusual. The reason for use of passive microwave devices as opposed to active is partly that they provide information about temperature which is provided by active devices (such as radar) only in an extremely indirect way if at all. Another basic reason for use of radiometric devices is that they are interesting sources of what I will call composition data. It is often possible to deduce a good deal about the composition of material from microwave data.

What is passive microwave radiation? It is simply thermal radiation down in the very long wavelength limits. In the first expression on your sheet of equations note that as λT approaches infinity, the argument of the exponent becomes very small [the sheet of equations is Figure 1]. The net result is that at long wavelengths at high temperatures, we simply have the expression you see on the right hand side. You observe then that the

$$(1)\quad \left[\exp \frac{ch}{\lambda}\frac{1}{kT} - 1\right]^{-1} \longrightarrow \frac{\lambda}{ch}\, kT$$

$$(2)\quad p(\lambda, d\lambda) = \epsilon\, \frac{2\,c\,d\lambda}{\lambda^4}\, kT = \epsilon\, \frac{2\,\Delta f}{\lambda^2}\, kT$$

$$(3)\quad P_{\Delta f} = \frac{k\,\Delta f}{4\,\pi} \int_{\Omega} G\, T\, \epsilon\, d\,\Omega$$

$$(4)\quad T_{app} = (1 - \epsilon)\, T_{inc} + \epsilon \int_0^{\infty} a(x)\, T(x) \left[\exp - \int_0^{x} a(x')\, dx'\right] dx$$

$$(5)\quad \sigma_T = K_{mod}\, \frac{T_{meas} + T_n}{(\tau\, \Delta f)^{1/2}}$$

Figure 1

blackbody radiation is proportional to wavelength and to temperature. This gives you the transposition between the infrared region where you worry about the Wien temperature and the forth power law and the microwave region where you are concerned about the first power of temperature. In the second equation we have a fairly familiar expression which is the power per unit solid angle per unit source area. Multiplication by ϵ signifies that we are considering a graybody rather than a blackbody. We find that the amount of energy in the interval $d\lambda$ is proportional to that interval, which by implication, means that it is also proportional to the increment of frequency df which is the expression following. Then we have for radiation from a gray surface proportionality to emissivity, to the bandwidth of the receiver, and to the temperature in degrees Kelvin. In the next expression we run into what I will call the antenna effect. We face two problems. In one case the target or object of interest fills the entire beam or scanning space in which case the entire beam is effectively in a mono-temperature zone; and the term $\frac{1}{\lambda^2}$ is of very little significance, because the antennas which we are dealing with have a radiation gain which also goes as λ^2. The net result is to cancel out the term $\frac{1}{\lambda^2}$. This is shown in equation three where we have the expression for the power into the receiver of bandwidth Δf shown as proportional to the Boltzman constant, k, times the bandwidth, Δf, which is an integral over the solid angle from which the radiation is coming multiplied by the temperature of the emitting surface at that point and by the emissivity at that point. If we have a number of targets in the beam, then we have an interval over a number of contributing surfaces. The final expression states that the power at the receiver is proportional to $kt\Delta f\epsilon$. This is for case one when the object literally fills the beam. Apparent temperature is easily defined as the temperature at which the radiation would be the same if ϵ were equal to one.

Now suppose there is only a very small target in the beam. Everything else in the beam contributes radiation as well. The fortuitous case is the one which the astronomer deals with most of the time in which the sky is a cold object. It produces radiation equivalent to a temperature of only a few degrees Kelvin in the microwave region while the object which he is looking for produces a relatively high radiation temperature. So he deals with a relatively hot spot in a very large background which is cold. Under these conditions it is obvious that the apparent temperature as seen by the radiometer is very close to that of the open sky increased only very slightly by the presence of an additional target.

References are normally made to situations in which the target fills the entire beam. The emission versus reflection problem also arises. In most applications of infrared, one thinks in terms of emission only from the surface in accordance with the emissivity of the surface. In photography the reflection component is the entire consideration. There is a negligible amount of self-emission at optical wavelengths. In the far-infrared you generally ignore the illumination and in the microwave case we have a lot of both.

Figure 2, which is a rudimentary figure, shows the emissivity component of rays coming out of the material, say at the bottom, some being scattered back inside the material again at the interface and some going on out into the air say at the top part of the figure. This is the ϵ figure. The second component is the $1 - \epsilon$ figure or reflective component bouncing off the surface. In practice we deal with non-uniform or inhomogeneous substrata. In equation four we have in a sense expressed the contributions from the incident component and the internal component. The integral contains the contributions from all contributing sources throughout the material assuming in this case that each individual source is attenuated by the layers between it and the surface and that each

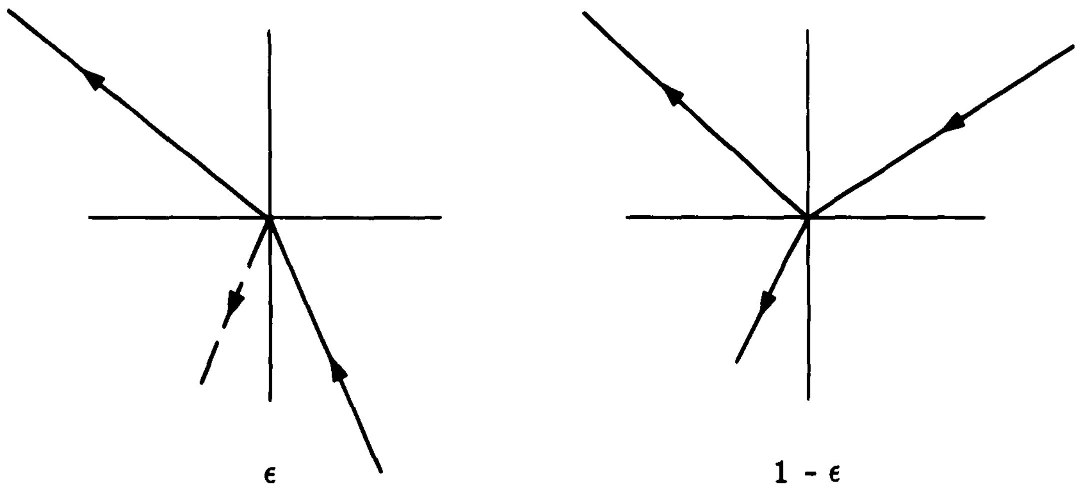

FIGURE 2

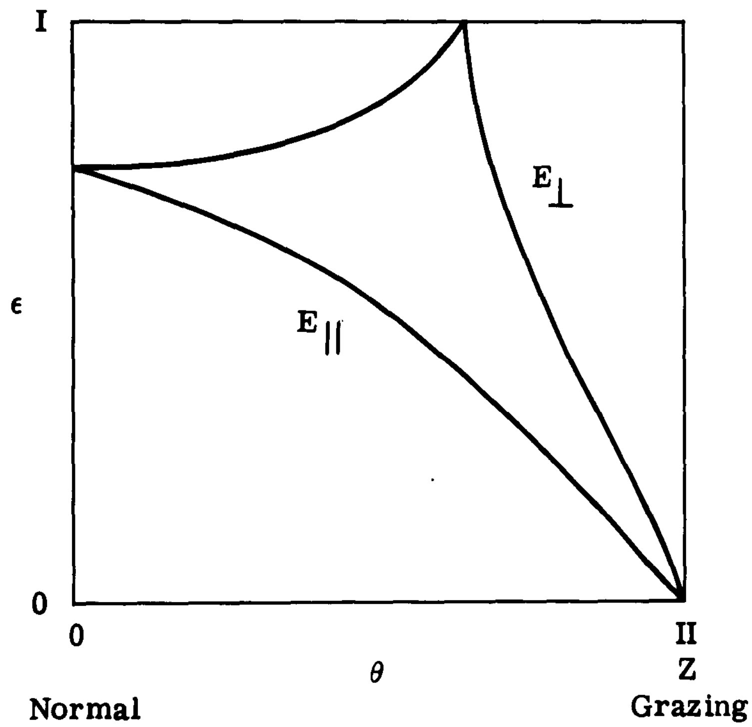

FIGURE 3

individual layer furthermore contributes its own radiation. This simplified treatment shows that in deep layers contributions come from well below the surface and the magnitude of the contributions are essentially proportional to the absorption in the layer. Penetration, therefore, is feasible as long as the penetration constant is not too large. An example of this is ice in which the attenuation constant for centimeter radiation is such that the $\frac{1}{e}$ drop occurs in about the first meter of depth. This varies with water content and various other impurities. So it is possible to penetrate a fair distance into natural materials with microwave radiation.

Polarization is very much a factor in establishing what the emissivity is and, therefore, what the radiating properties are. In Figure 3 you will see that for a typical surface the component in which the E vector is parallel to the surface is associated with a decreasing emissivity as we move from normal incidence to grazing incidence. At grazing incidence almost any surface is a fairly good reflector. The wave which has a portion of its radiation polarized so that the E vector in part penetrates into the surface exhibits the Brewster effect in which normally the emissivity rises to unity at some angle off normal and then drops off to zero again. So it is easy to see that for a surface like water, for which this graph was originally drawn, looks very different according to the angle and the polarization used; and it is quite easy to identify a surface such as water.

I think it is obvious by now that in the passive microwave game, we can measure the product of emissivity times temperature. Stray radiation from other sources is at times a problem. Sometimes our problem is to measure either ϵ or T. We can in fact have contrasts in emissivity or in temperature. In the passive microwave region we have a wonderful illuminator in the cold galaxy or outer space. The radiation temperature of the sky looking toward the Zenith over a wide frequency band is very close to zero

and so we have a negative illuminator so to speak. We see things very frequently not by the fact that they are bright, but by the fact that they are dark. Variations in the sky temperature are, therefore, very important. The radiation temperature we see in a region of absorption is effectively the temperature of the atmosphere and at those wavelengths the gas temperature predominates over the sky temperature. A second important consideration is rain scatter. During rainfall, even though the rain drops do not necessarily attenuate the radiation much, they do scatter the radiation. On a wavelength scale starting in the millimeter range, we find that the sky temperature is normally $10^{6°}$ K or higher. The curve is rising approximately proportional to the 2.5 power of the wavelength. The minimum of the curve is in the general vicinity of 10 centimeters. Earth noise is another nasty problem. Important noises are produced by thunderstorms and lightning discharges. TV transmitters and ham radio stations are other very important sources of noise.

The information which we can deduce from passive microwave data obviously depends on the purpose at hand. You are all familiar with radio astronomy and with the fact that the astronomers have found the wonderful new diversion of measuring all the planets and stars. The microwave instrument gives the astronomers a direct clue to the surface composition. It allows them to penetrate at least a moderate distance into the surface of the moon.

On this page which I am passing out, you will see a picture taken a number of years ago with what I would call an abominable radiometer. You are looking down on a lake out in western Massachusetts from an airplane flying not high above it with a scanning radiometer which produced a scanning map as the aircraft flew over the reservoir which is a few miles long and perhaps a mile or two wide. You will observe that it looks like a very badly focused photographic shot of a lake or a tunnel. The picture was

made with very poor thermal and angular resolution. In problems of satellite operation there are problems associated with operating 600 miles above the earth and some of the applications so far to satellites have been pretty rudimentary. Probably the most discussed one has been in the area of the measurement of the composition of the earth's atmosphere by use of radiometer techniques. In spite of the lack of familiarity with microwave radiometry and in spite of the fact that it is still in an early stage of development, some of the statements made yesterday are very pertinent. Radiometers can do all of the things mentioned in Mr. Parker's paper of yesterday with very limited capability.

We will consider here some of the problems associated with radiometry. A terrain map is feasible as I have shown you in the illustration from Aviation Week. That article gives the temperature differences associated with certain materials but none of the numbers are to be believed in themselves, because if you change one of the parameters a little bit, the numbers are likely to change considerably. Nevertheless differences do exist and they are reasonably consistent.

As another example suppose we are trying to measure temperature gradients [in the atmosphere]. We are looking for temperature differences of the order of roughly 3 or 4° per thousand feet of rise. In radio astronomy, using the big dishes, one has to measure with a temperature sensitivity of the order of 1/100 of a degree Kelvin which pushes the radiometer designer rather hard.

Now resolution is probably the worst problem. For a terrain map, for example, one would like to have pretty good resolution comparable to that of a photograph. This, of course, is not possible. In crevasse detection, one would like to have rather fine resolution as some crevasses are quite narrow. In a satellite application, on the other hand, one might like to know whether the satellite is over land or over ocean. In this

case resolution is a relatively minor item. The problem of angular resolution depends upon the matter at hand, but usually it is a nasty one.

Now how is the radiation measured? The basic concept is fairly simple. We have incoherent radiation coming in; and to get an accurate measurement of incoherent radiation, it is necessary to take an extremely large number of independent samples. For example, with a bandwidth of a megacycle we are effectively taking one million independent measurements of the radiation itself per second. We consider here something like the central limit theorem which says that for a very large number of samples, the standard deviation in the measurement divided by the value measured goes down as $\frac{1}{\sqrt{N}}$. This means that for a million samples we can measure approximately to the square root of that or 10^{-3} on temperature measurements. You can easily see that normally you have to have very wide band receivers in order to make these measurements. In equation five, the standard deviation in temperature is equal to K_{mod}, where K_{mod} is normally equal to about one times the expression in brackets. It is obvious from looking at expression five that first of all it is nice to go slowly in order to have a long time constant in integration, and it is nice to have a wide bandwidth. That, by implication, requires a high operating frequency since it is hard to get more bandwidth than the center frequency. We should also like to have a very quiet receiver to reduce the T_n term.

Let me now give you some examples of sensitivity. For a receiver typical of some of the early experiments a noise temperature of 3000 to 10,000 degrees K is appropriate. Bandwidth was approximately 10 megacycles, integrating time constant was approximately one second, and the value of K_{mod} was about 4. The net result of this is a standard deviation in temperature of about 4^{o}. Therefore, this type of radiometer was capable of measuring temperature differentials of the order of $10^{o}K$. Instruments which have become

available in the last couple of years can do much better than this. Noise temperatures have dropped an order of magnitude, down to about 500°; bandwidth is up to around 1000 megacycles; time constant is about 10^{-2} sec; and K_{mod} equals about 2. This results in temperature measurement capability to about one-half degree. Comparatively, the radio astronomers have a much simpler job. They have available to them some very beautiful new maser receivers with noise temperatures of well below 300°, and 100° is not at all uncommon. Bandwidth is a few hundred megacycles and time constants of 50 to 100 seconds are not uncommonly used, while the modulation factors are of the order of 1, 2, 3, or 4. This results in a standard deviation temperature measurement of somewhere between 1/1000° and 1/100°. Now the thing which creeps up fastest in the old receivers and even in the new ones is called gain fluctuation noise. When you try to measure 10 million samples and average over this number of samples if the amplifier gain fluctuates slowly in sensitivity, shifts in the apparent temperature measurement can result. For example, a change in gain of one part in a thousand for a receiver with a noise temperature of about 100° is going to give about 1/10° variation; and it is obvious that these gain fluctuations have to be held down by proper design. [There is a small section of the talk missing here . . . .] with a chopping device, what we effectively do is to put in two signals to the receiver and switch between them alternately. We then make a subtraction between the two. In terms of probability the net result of subtracting is to add the variance so K_{mod} is something like 2 at best if we use chopping devices and normally 3 or 4 because of bandwidth limitations on the chopper. In the DC radiometer, K_{mod} is only one, but such radiometers are only used where gain stability is not a problem.

Returning to the problem of angular beam width, you are quite well aware that for a diffraction limited antenna the resolution is nominally equal to $\frac{\lambda}{d}$. A result of this is

as follows: suppose, for example, that we are in a satellite looking down on the earth at a range of 500 kilometers and let us assume a wavelength of 1/10 of a meter which is somewhere near the bottom of this atmospheric attenuation curve. What is the size of the resolution patch which we see on the ground? The answer is about 1 1/2 kilometers. To get this figure, however, we must assume an aperature size of approximately 100 feet. At the other end of the scale consider an altitude of 100 meters above the ground which may be appropriate for oil prospecting and other purposes and use a wavelength of one centimeter with an antenna size of approximately 1 meter. The resolution on the ground is about 1 meter. Although there are many antennas available design-wise, unfortunately, they are all too big. We can receive direct radiation from a star or reflected radiation from the ground. We can, under these conditions, record the wide-band signal from the direct reception; then when the bounce reception comes in, correlate against that over a wide frequency band. This can give a lot of resolution. It is like having a radar with a star as a transmitter. There are some techniques along this line which have been used very successfully in optical astronomy as typified by the work of Handbury Brown [?] and others in recent issues of the Physical Review. That has not, however, become a very active phase of the subject. What are the applications so far then? In astronomy temperature measurements are the essential ones. An enormous antenna is usually used. These range in size from the 600 foot Green Bank antenna to ones like the 84 foot antenna used at the University of Michigan. We are vying with the Russians for who can build the biggest antenna.

I have shown you a miserable radiograph taken from an aircraft. It does show land-water contrasts rather uniquely. As for geological applications, I mentioned earlier that we have discussed the subject of locating crevasses and glaciers which is an interesting possibility. Other prople have discussed measurements of the ocean currents, the location

of the Gulf Stream--where does it go and how does it weave and meander? There are also interests in things like iceberg detections and the determination of sand moisture. The penetration of microwave radiation into dry sand is actually fairly good. The amount of work on this is limited in two ways. First it is limited because people haven't done very much; second it is limited in that I don't know about all of it. Meteorological applications are just beginning to open up and I think that much more will be done. It is quite obvious that there is a thermal gradient in the atmosphere which is related to the density gradient and there are radiation lines which vary from extremely sharp lines such as that of oxygen to very broad lines such as the 1 centimeter microwave line or the 2 millimeter microwave line. There is also a chance of measuring the variation of temperature with wavelength over small temperature ranges where a known signal mechanism is causing the change in transmission. Those are some of the basic areas.

Now who is active in this field? First the universities are very active in astronomy and a great many of advances in the art have derived from their work. Studies of surfaces have more recently been carried out by universities. The military departments have their own interests which I will not go into. Industry is in general working on hardware; for example, there will be available a maser receiver which will have about 100 megacycles bandwidth at a wavelength of about 1 centimeter or shorter with a noise temperature well down in the 3^{o} Kelvin area as long as one can freeze all the rest of the microwave components around it. So this type of thing is coming into being. There are developments in such things as parametric amplifiers. Industry is progressing also on antenna design although, as I say, they are all too big. Another area that industry is active in is, of course, the various applications. In summary then, what people are shooting for is to take advantage of propagation and of penetration which other wavelengths simply don't get into, trying to take

advantage of the fact that temperature is a parameter which by being involved can be measured also, and trying to produce information on composition. The worst problems are probably resolution angle and scanning speed. It is, however, a major field; and we should look forward to important advancements in the next few years.

Robert Moxham: You mentioned penetration of dry sand. Can you discuss further the possibility of a second emitting surface below the sand?

Wes Vivian: The problem is that the data on sand and gravel are conflicting and inadequate. I can find numbers which can prove anything. Penetrations from 0.1 inch to 12 meters can be calculated. There are usually too many uncontrolled variables in the experiments. At wavelengths of around tens of centimeters to a couple of meters, I think you will find penetrations on the order of a magnitude of a meter. It depends very heavily on the type of sand.

Question: I have heard of some work in this area around 8 to 12 kilomegacycles. Can you tell me what frequencies you refer to?

[The answer is unintelligible.]

Question: How close are the apparent density measurements to the actual density . . . .?

Wes Vivian: Well the temperature of a good metal roof might be measured as 5 to 10° Kelvin. The combination of emissivity and temperatures counts.

RADAR RING "ANGELS"*

James M. Wolf

Radars sometimes show an echo, which resembles the echo from an airplane or ship, when in fact there is no such object present at the indicated distance and direction. In some cases there are known to be due to simple causes, such as reflection from the side of a nearby ship to the target, and back by the same path. This puts a mirror image of the target onto the display, and these false images have caused many futile chases after objects not present. It became the practice to call such spectral targets "ghosts." As radars were made more powerful and more sensitive, a class of weaker "false" echoes was found which could not be explained as simply. These were believed due to irregularities in the atmosphere and were irreverently called "angels."

Many atmospheric phenomena can be seen by radar including thunderstorms and zones in which snow is melting. It is thus not improbable that there is a meteorological explanation for certain of these angels.

In the summer of 1955, we observed in my laboratory a very peculiar radar angel of a new type. We were using a powerful radar adjusted to present echoes from objects at relatively short ranges, a somewhat unusual procedure. It was equipped with a device which suppresses the echoes from objects that are not in motion so that the echo from the earth would not interfere with the observation of moving airplanes.

This peculiar angel was of the form of an expanding ring, centered about ten miles south of our radar site at Willow Run Airport. The radius of the ring expanded at a rate

*The research reported in this paper was conducted under Project MICHIGAN, then a Tri-Service Contract (DA-36-039-SC-52654) sponsored by the Department of the Army and Administered by the U. S. Army Signal Corps.

of about forty miles an hour; it grew to about thirty miles in diameter passing through the radar location in the process. We began looking for these rings and found that they could be seen quite commonly though they were usually not as large and perfect as the first one that was noted. During the working day they seemed most numerous in later afternoon.

I had some time-lapse pictures made of this phenomenon, and I will show them to you. [A film documenting the phenomenon was shown at this time.] Each frame of this motion picture film represents one 360° scan of the radar antenna. The radar is at the central bright spot, and the range to the edge of the circle is about 20 nautical miles. The circular range markers are at ten nautical mile intervals. The pictures were made at a rate of three per minute and are projected at about twenty per second; thus the time speed-up is about four hundred to one. The echoes are presented as bright spots on a dark field. The rapidly moving objects that resemble flies are airplanes, speeded up.

When I presented this film at a classified radar symposium in February 1956, I hypothesized that the rings might be waves between atmospheric layers, spreading like a ripple in a millpond. In at least one instance in the film, an aircraft passed through the center as the ring appeared. Perhaps the wave was seen directly, or perhaps the ground was seen imaged in a wave at half distance. There is nothing unusual on the ground at the center of the ring, nor at half range.

Subsequently Mr. Floyd Elder, a professional meteorologist in our organization, published an analysis of the film record with accompanying meteorological data. His computations indicated that waves of a speed matching the rings might be a possibility. On the other hand, the presence of the necessary layer was not confirmed; and in fact, the rings were seen under a great diversity of weather conditions.

It had been reported earlier that birds were among the causes of radar angels, and this is now well established . Birds were frequently seen by radar at short ranges during the war. Subsequently similar ring angels were observed both in Texas and in England; and in both cases, birds are shown to be the cause. In Texas the redwing blackbird produced a loose ring; in England starlings made rings closely resembling those we observed. The rings are produced as the birds leave their roosts. I presume the ring angels that I have shown you were also due to starlings, yet why they deploy in the afternoon in Michigan I do not know.

By now the study of bird movements by radar has become a part of ornithology; and I invite your attention to a review article in Natural History Magazine, October 1961, in which unsuspected results on bird migration, as revealed by radar, are presented.

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INFRARED TECHNOLOGY

Joseph Morgan

Historically, infrared research started with the pioneer work of William Herschel who demonstrated some 160 years ago the existence of thermal energy beyond the red part of the visible spectrum. It was nearly one hundred years later before any further serious work was done, and it has only been since World War II that development work on passive infrared devices has proceeded apace. The infrared region has since, of course, come to play an important role in military and space technology.

The first successful infrared imaging device was the evaporagraph, devised by Czerny in 1929. The evaporagraph was not a successful military device because it is fragile and has associated with it a long time constant, and may in fact have limited application in the field of remote sensing. One can determine with the evaporagraph temperature differentials of one-tenth degree centigrade and the resolution, corresponding to that of a photographic film, is about ten lines per millimeter. The airborne infrared reconnaissance scanner is a typical example of a military device which has potential application as a remote sensing equipment. The infrared strip maps or thermographs produced by the infrared scanner have generated a number of expressions of interest in the possibility of their application. Although military scanners have associated with their design parameters which require some reconsideration for terrain scanning purposes, no drastic redesign is required for optimization of existing scanners to non-military problems.

Prior to the inception of this study program, the infrared laboratory here had received inquiries concerning the possible application of infrared scanning and/or radiometry to a number of essentially non-military problems, including the following:

1. Surveillance of forested regions for early fire detection and for patrol of burned areas.

2. Determination of horizontal thermal gradients in water for such purposes as mapping the course of the Gulf Stream, location of water pollution sources, and studies of the influence of water temperature on the habits of fish.

3. Iceberg detection and counting and the analysis of sea ice.

4. Crevasse detection.

5. Thermal prospecting for minerals.

6. Determination of soil moisture content and water table.

7. Detection of subsurface geological structures and sources of hydrothermal activity.

8. Determination of disease in trees and fruit crops.

9. Detecton of surface thermal activity resulting from underground explosions and fires.

We have become aware of a number of active or planned projects in remote sensing, and there are undoubtedly others of which we have not been advised. These programs are not interrelated, and most are of a short-term nature. Examples of existing programs are:

1. A search by the U. S. Coast Guard for an all-weather iceberg detection and position plotting system. Current emphasis is on passive microwave techniques.

2. Forest fire detection: The Northern Fire Fighting Laboratory at Missoula, Montana, has recently acquired an infrared scanner from the Army Signal Corps for use in investigation of this possibility.

3. Measurement and mapping of sea surface temperature variations and sea ice reconnaissance, U. S. Naval Hydrographic Office.

4. The cooperative program between the Institute of Science and Technology through the U. S. Army Signal Corps and the U. S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory on the use of airborne infrared devices for crevasse detection, sea ice analysis, and detection of hydrothermal activity.

5. Studies of the geological structure of the lunar surface by the U. S. Geological Survey.

6. The well-known weather satellite program utilizing photographic and infrared imaging of cloud structure.

Detection and Measurement of Infrared Radiation

All variations in the amount of radiation emitted by various components of the terrain are traceable to differences in either emissivity or temperature or combinations of both. Emissivity is a basic physical property, often varying, however, with wavelength which may be determined once for all. Actual temperature variation is induced by many factors including the following, many combinations of which may predominate in importance depending on the environmental situation.

1. Wind
2. Heat capacity
3. Thermal conductivity
4. Surface to volume ratio
5. Moisture content and the evaporation process
6. Sky cover and its effect on radiation exchange
7. Topography and solar history
8. Elevation differences and the thermocline
9. Metabolism of plants
10. Dewfall and precipitation

For solid, non-transparent substance, the sum of reflectivity plus emissivity is unity; so every surface in nature reflects a certain amount of radiation from the surroundings which must often be taken into consideration, depending upon the circumstances of the measurement.

Some definitions of terminology are in order at this point. Expressions involving radiative properties of materials are referred to the radiation characteristics of a theoretically perfect blackbody. Blackbody radiation is defined as that which exists in an enclosure whose walls are at a uniform temperature. This is a classical and precise definition of blackbody radiation. The energy density inside the enclosure and its wavelength distribution are a function of the temperature only. The total energy emerging from a small opening in such an enclosure at absolute temperature T into a hemisphere is given by the Stefan-Boltzmann Law:

$$W = \sigma T^4 \text{ watts/cm}^2.$$

To gain a feeling for the magnitude of this radiation, we note that a blackbody at room temperature ($300^{o}K$) emits some 460 watts per square meter; for every degree of temperature increase, an extra 6.2 watts are emitted. We see that the total radiation from a blackbody surface is by no means negligible. It is, in fact, quite intense. There is plenty of electromagnetic energy available for measurement. The wavelength distribution of blackbody radiation was determined, after many empirical labors by others, by Max Planck. The well-known Planck equation is practically never used directly because it is hard to work with. Simple slide rules are available today which yield all the results of an otherwise laborious computation process.

If we differentiate the Planck equation with respect to wavelength and set the derivative equal to zero, we obtain λ_m, the wavelength at which the energy is a maximum.

where $K = 2897$ micron degrees.

This is Wien's displacement law. It shows the position of the peak of the energy distribution curve for a black or gray body source.

Any surface which completely absorbs all the radiation incident upon it will emit radiation in accordance with Planck's Law and is said to have unit emissivity. Most surfaces encountered in nature, however, are only fair approximations of a blackbody; and some have emissivity values substantially less than unity. The Stefan-Boltzmann Law becomes $W = \epsilon\sigma T^4$ for non-blackbody surfaces, where ϵ is the effective emissivity of the body. In actuality, ϵ is usually a function of wavelength and must often be evaluated for different portions of the spectrum. All water substances (vapor, liquid, snow and ice) present nearly perfect blackbody surfaces all having values of ϵ in excess of 0.95. Most other naturally occurring surfaces have emissivities in excess of 0.7 throughout the infrared, while man-made or cultural features often present surfaces of extremely low emissivity.

The only other factors worth mentioning at this point are that the radiant intensity from a point source falls off with range in accordance with the inverse square law, and that the radiation received from a plane surface varies as the cosine of the angle between the line of sight and the normal to the surface. The latter is Lambert's cosine law. Since the average value of the cosine function over the hemisphere is 0.5, we must divide W by π if we wish to determine watts per square centimeter per steradian emitted by a blackbody surface in a normal direction. Thus, for example, a 300°K blackbody emits $460/\pi$ = 148 watts/m^2 steradian in a direction normal to its surface. Much of what I will have to say is presented in detail in a forthcoming book concerning the fundamentals of infrared technology.[1]

Atmospheric Transmission

The effects of the earth's atmosphere must be seriously considered in the design and use of infrared sensing equipments. The infrared radiation incident on a receiver is often extensively modified by the intervening atmosphere which is an inhomogeneous and continuously changing mixture of gases, liquid droplets, and particulate solid matter. The gases of primary interest are water vapor (H_20), carbon dioxide ($C0_2$), nitrous oxide (N_20), and ozone (0_3). These gases will absorb and emit radiation as a function, among other things, of the number of molecules present, the wavelength involved, and the energy states of the molecules. The prediction of scattering effects is made difficult by the fact that the applicable scattering theories require knowledge of particle numbers, densities, shapes, sizes, and electrical characteristics which depend on the materials that make up the particles. These parameters are not easily determined, and the theory cannot take all of the factors into account unless many simplifying assumptions are made. The transmitted radiation is also subject to refraction by the medium traversed. Absorption, emission, scattering, and refraction all vary with time and space throughout the path of transmission. The constant motion of the atmosphere, on both micro and macroscopic scales, create these variations in as unpredictable a pattern as the variations in other meteorological parameters. Only on a statistical basis is any prediction possible.

In spite of the complexity of the problem, a useful insight might be obtained by an understanding of the fundamental physical processes involved. The absorption and emission spectra of the more important gases are describable in the regions of interest. Meteorologists and climatologists tell us much about the composition of the atmosphere and what is known about its variations. Theories of scattering and refraction have been developed and employed with some success, particularly in the often encountered cases

in which these are secondary effects. Finally, there exist several measurements of the transmittance, at wavelengths from 0.7μ to beyond 15 μ, of real and synthetic atmospheres. These works constitute the heart of the attack on the problem of atmospheric effects in the infrared region. The paper by W. Elsasser[2], listed among the references, is now considered by many to be a classic in this field. Another very important paper, by Elder and Strong[3], presented in 1953 the results of an ONR (Office of Naval Research) sponsored research program. In 1956, Naval Research Laboratory Report 4759 was issued to present measurements by Taylor and Yates of the spectral atmospheric transmission from 0.8 to 15 μ over paths of 1000 feet, 3.4 miles, and 10.1 miles over Chesapeake Bay. This excellent paper contains a significant portion of the best experimental field data available today. Calculation of atmospheric transmission over long paths at sea level are best made by interpolation of these data.

Figure 1 indicates how the infrared spectrum is roughly broken down into three regions, while temperatures corresponding to peak blackbody radiation are shown in the tabular data. Figure 2 summarizes the sources of radiation which must be taken into consideration when dealing with the target against its background and in the presence of sunlight.

The attenuating effects of the atmosphere may usually be computed with fair accuracy if the temperature and humidity are known, provided that the wavelength region utilized falls within one of the highly transparent "window" regions of the spectrum. It should also be noted here that the transmission through clouds, rain, fog and other obstructions to visibility is little better for infrared radiation than for visible light. The longer wavelength of infrared reduces the scattering effect, but water droplets and snow are very strong absorbers.

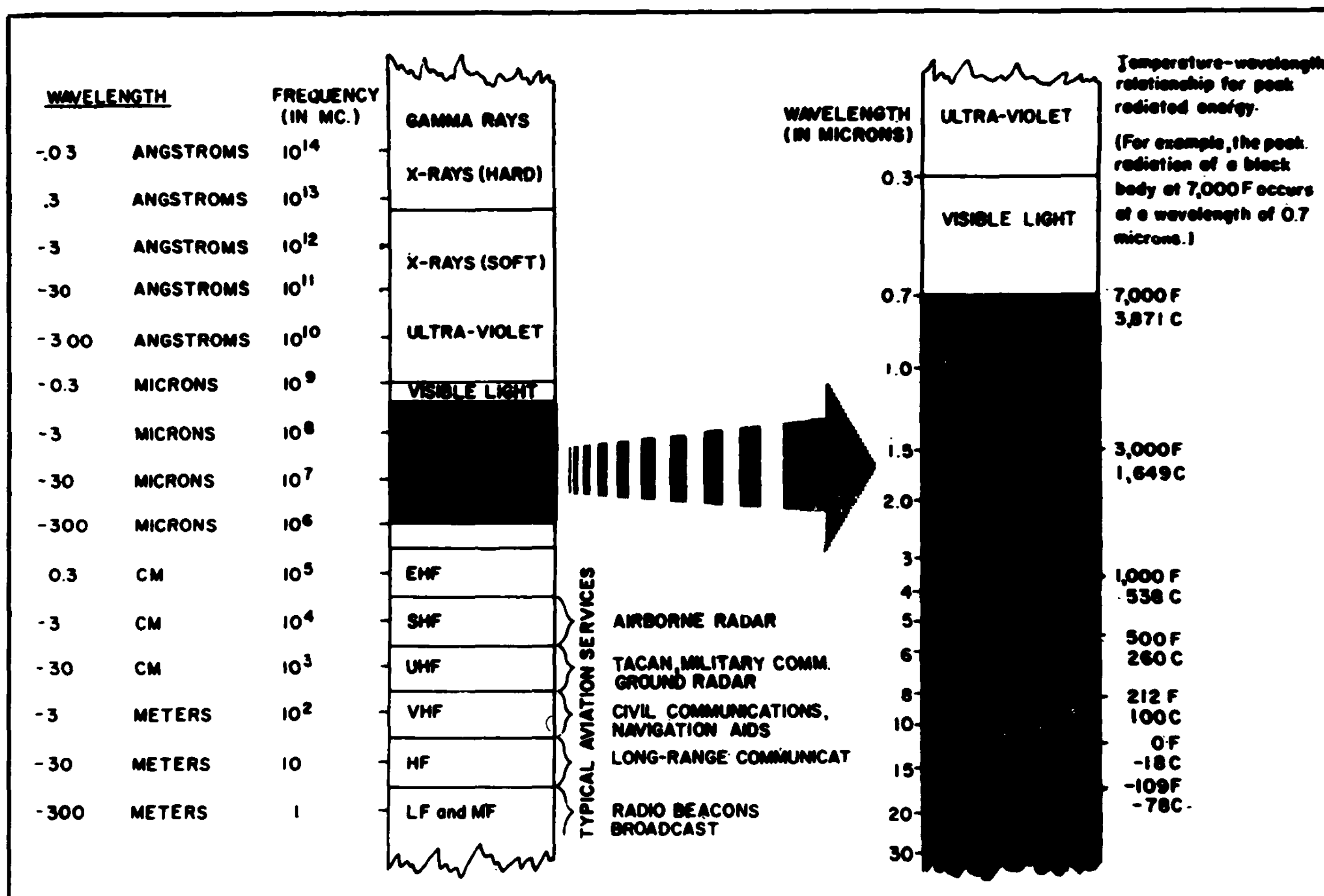

WAVELENGTH
FREQUENCY (IN MC.)
-.03 ANGSTROMS 10^{14}
.3 ANGSTROMS 10^{13}
-3 ANGSTROMS 10^{12}
-30 ANGSTROMS 10^{11}
-300 ANGSTROMS 10^{10}
-0.3 MICRONS 10^{9}
-3 MICRONS 10^{8}
-30 MICRONS 10^{7}
-300 MICRONS 10^{6}
0.3 CM 10^{5}
-3 CM 10^{4}
-30 CM 10^{3}
-3 METERS 10^{2}
-30 METERS 10
-300 METERS 1
GAMMA RAYS
X-RAYS (HARD)
X-RAYS (SOFT)
ULTRA-VIOLET
VISIBLE LIGHT
EHF
SHF
UHF
VHF
HF
LF and MF
TYPICAL AVIATION SERVICES
AIRBORNE RADAR
TACAN, MILITARY COMM. GROUND RADAR
CIVIL COMMUNICATIONS, NAVIGATION AIDS
LONG-RANGE COMMUNICAT
RADIO BEACONS BROADCAST
WAVELENGTH (IN MICRONS)
ULTRA-VIOLET
VISIBLE LIGHT
0.3
0.7
1.0
1.5
2.0
3
4
5
6
8
10
15
20
30
Temperature-wavelength relationship for peak radiated energy.
(For example, the peak radiation of a black body at 7,000 F occurs at a wavelength of 0.7 microns.)
7,000 F 3,871 C
3,000F 1,649C
1,000 F 538 C
500 F 260 C
212 F 100C
0F -18C
-109F -78C

FIGURE 1

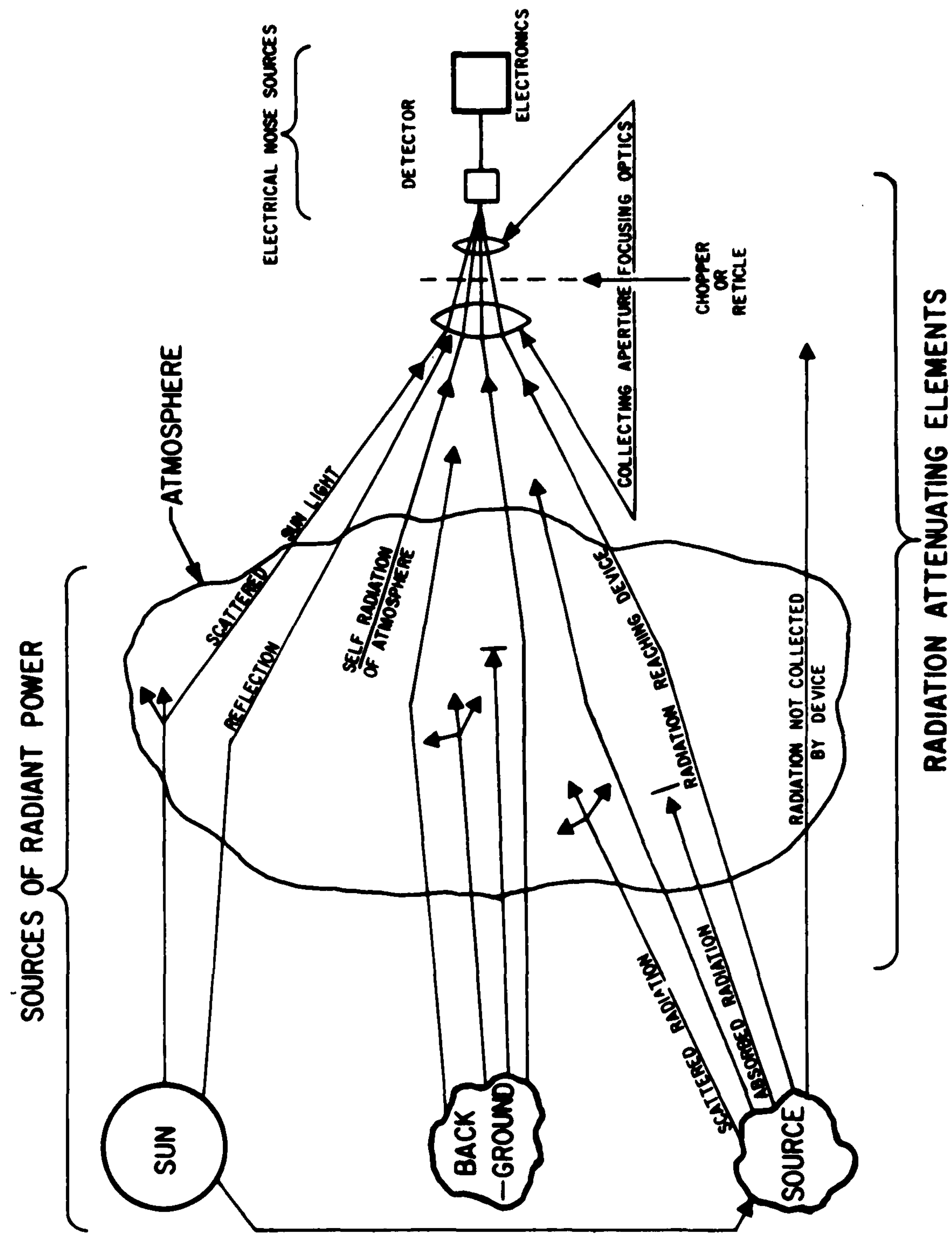

SOURCES OF RADIANT POWER
RADIATION ATTENUATING ELEMENTS
ELECTRICAL NOISE SOURCES
ATMOSPHERE
SCATTERED SUN LIGHT
REFLECTION
SELF RADIATION OF ATMOSPHERE
RADIATION REACHING DEVICE
RADIATION NOT COLLECTED BY DEVICE
SCATTERED RADIATION
ABSORBED RADIATION
SUN
BACK-GROUND
SOURCE
COLLECTING APERTURE
FOCUSING OPTICS
CHOPPER OR RETICLE
DETECTOR
ELECTRONICS

FIGURE 2

While the problem of atmospheric transmission has been attacked vigorously and with considerable success, measurements of emissivity and reflectivity of natural materials have not been carried out in impressive quantity and often not with adequate precision. Some of the work which has been done has been carried out in the laboratory under unrealistic conditions. We feel that there remains much field research to be done in this area, as the influence of meteorological parameters on these values must be determined. These measurements should be made in every case in one of the regions of high atmospheric transparency.

Detectors

Of the two primary classes of detectors--the thermal types, characterized by the bolometer and the thermocouple, and the photoelectric types--we will only consider the photoelectric detectors here, because the other types lack both sensitivity and speed of response for high-speed measurements from an aircraft. I shall only mention the most relevant parameters and why they are important. Detector development has proceeded from shorter to longer wavelengths, culminating recently in successful execution of sensitive high-speed detectors which can be used in the famous broad atmospheric window between 8 and 14 μ. Figure 3 shows several relevant relationships in a qualitative way. Assuming a reflection coefficient for sunlight of 0.2, the cross-over point between reflected sunshine and emitted terrestrial radiation occurs at about 3.5 μ. Filtering must be complete below this point in order to secure legitimate thermographs of the terrain in daytime. Note that lead sulfide has hardly any response beyond the region of reflected sunlight while lead selenide and lead telluride, properly filtered, are capable of producing true thermographs. Indium antimonide is a newer, more sensitive development with a much shorter time constant which works very well in the region between 4.5 and 6 μ. Note that gold-doped

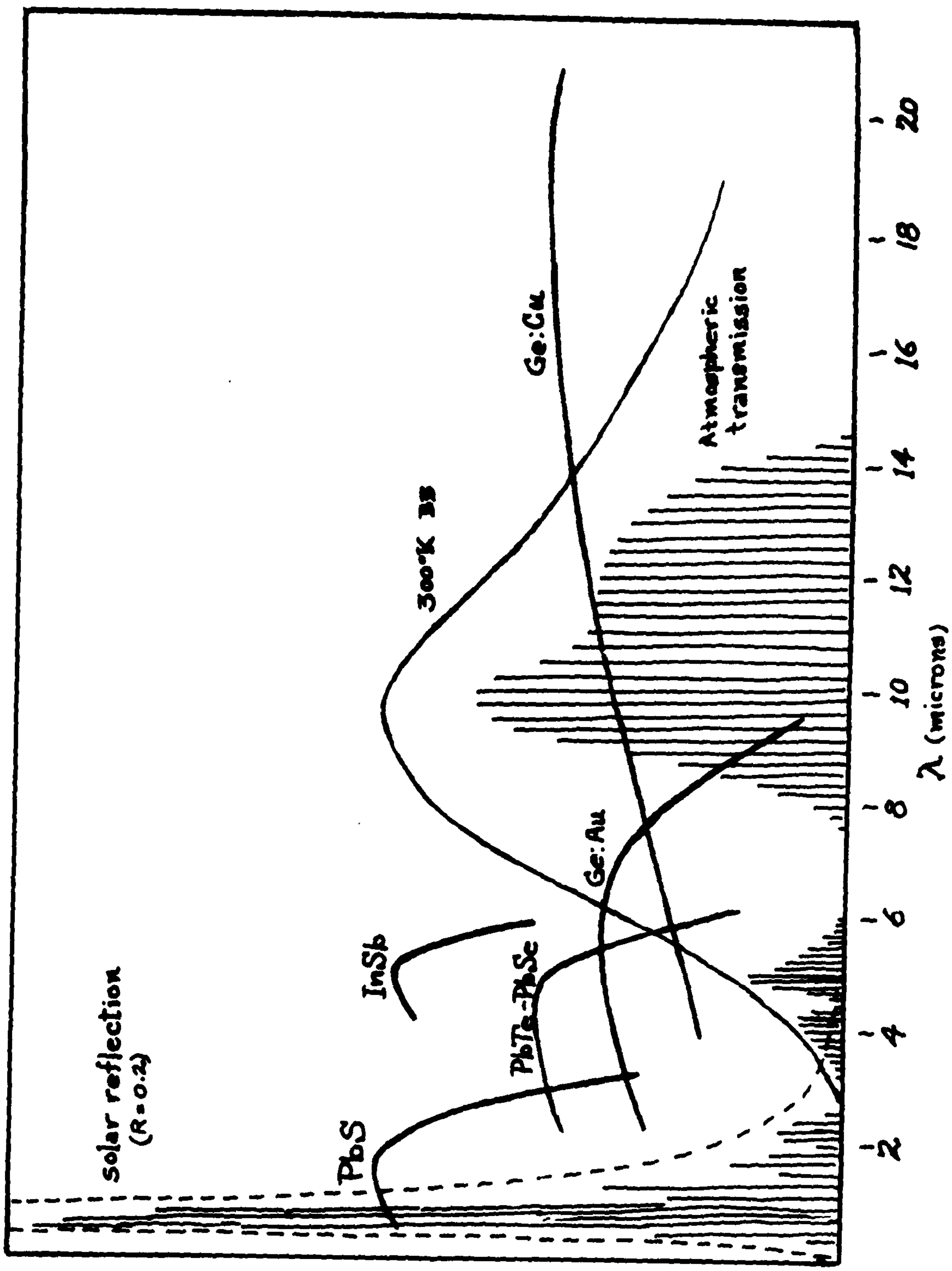

Solar reflection
(R=0.2)
PbS
InSb
PbTe-PbSe
Ge:Au
300°K BB
Ge:Cu
Atmospheric
transmission
2
4
6
8
10
12
14
16
18
20
λ (microns)

FIGURE 3

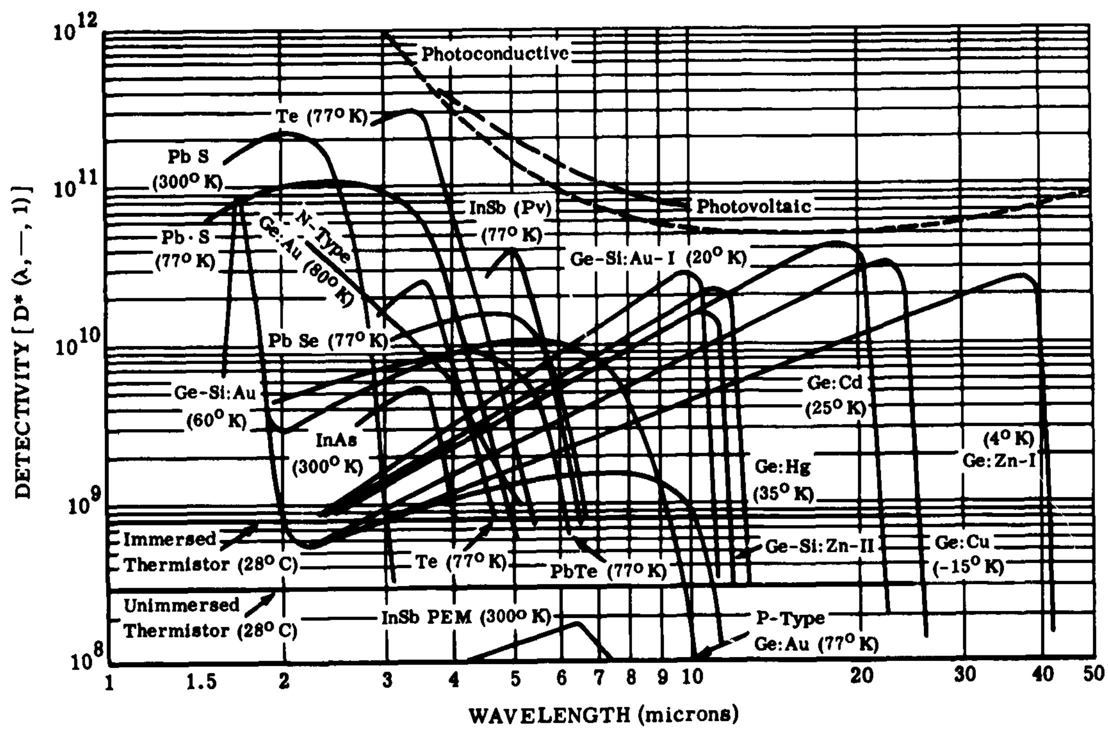
germanium is not very useful because most of its sensitivity lies in a region of complete atmospheric absorption. The newer cells, typified here by copper-doped germanium, have at long last made this long wavelength window available; and this is doubly important because of the excellent transparency of the region and because the largest amount of black-body radiation from the earth occurs at these wavelengths.

Detectors are usually characterized by a statement of the noise equivalent power. The most used expression at present is one credited to R. Clark Jones which was originally written as

$$D^* = \frac{\sqrt{A} \cdot \Delta f}{NEP},$$ the detectivity normalized to unit area and unit bandwidth.

The best detectors have D* values which indicate that one can measure, at least in principle, 10^{-12} watts of radiation. This shows that it is possible to measure very small variations in the radiation emitted by an ambient temperature source. It may be appropriate to mention here the characteristics of a typical copper-doped germanium detector. This detector must be operated at a temperature close to that of liquid helium, i.e., 4.2°K, and not above 20°K in order to reduce thermal noise to an acceptable value. D* is typically 10^9 to 10^{10}, depending upon the detector geometry. The time constant is less than one microsecond, and the responsivity is approximately 8000 volts per watt.

Figure 4 is shown only to illustrate the degree of activity in the field of detector development. With few exceptions these curves represent relatively recent developments. Note the position occupied by the thermistor bolometer which has the single virtue of flat response throughout the infrared provided the surface is properly blackened. This is not to say that all these detectors are commercially available today, but the situation is improving steadily. The new detectors are, for the most part, quiet and easy to operate.



10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
DETECTIVITY [D* (λ, —, 1)]
Photoconductive
Te (77° K)
Pb S
(300° K)
InSb (Pv)
(77° K)
Photovoltaic
Pb · S
(77° K)
N-Type
Ge:Au (80° K)
Ge-Si:Au-I (20° K)
Pb Se (77° K)
Ge-Si:Au
(60° K)
InAs
(300° K)
Ge:Cd
(25° K)
Ge:Hg
(35° K)
(4° K)
Ge:Zn-I
Immersed
Thermistor (28° C)
Te (77° K)
PbTe (77° K)
Ge-Si:Zn-II
Ge:Cu
(-15° K)
Unimmersed
Thermistor (28° C)
InSb PEM (300° K)
P-Type
Ge:Au (77° K)
1
1.5
2
3
4
5
6
7
8
9
10
20
30
40
50
WAVELENGTH (microns)

FIGURE 4

In practice it is often important to employ filters to eliminate reflected sunlight and to restrict the wavelength region to one at the highly transparent windows in the atmosphere.

Radiometry

Any one of these detectors provided with an elementary optical system and proper electronics and recording apparatus is capable, at least in principal, of quantitative measurement. In practice radiometric measurements made with good accuracy are not altogether simple to acquire. Typical radiometers, equipped with fast collecting optics and appropriate chopping systems, are described throughout the literature. The relevant facts about the radiometer as a remote sensing device are that, subject to limitations already discussed, energy variations corresponding to temperatures of a small fraction of a degree are measurable, the instantaneous field of view may be made nearly as small as you please, and the speed of data acquisition may be impressive with a fast detector. To illustrate this latter point, a typical radiometer with an angular field of view of 5 milliradians and a detector time constant of 1 microsecond, operated in an aircraft at an altitude of 1000 feet would have a ground resolution of 5 feet and would measure the radiation from a patch of terrain 5 feet square. Allowing for a dwell time of 3 microseconds (i.e., any point on the ground remains within the field of view of the radiometer for 3 microseconds), the maximum permissible speed of the aircraft is about 10^6 miles per hour to make full use of the information gathering capability. It might be wiser to arrange the radiometer for scanning from side to side as the airplane moves forward, than to consider construction of a 10^6 mile per hour airborne platform. For an airplane with a cruising speed of 300 miles per hour, we have a factor of 3×10^3 in hand; and by scanning with 100 percent efficiency, one could cover all the ground beneath the aircraft in a strip 15,000 feet wide as compared

to the 5 foot strip traced out by the non-scanning radiometer. The rate of coverage is approximately 1000 square miles per hour which is a typical value for a modern infrared scanner. Having converted the radiometer to a scanner, we now have a choice of continuous chart or magnetic tape recording; or by modulating the scanner signal to operate a cathode ray tube, we can generate a picture using circuitry very much like that of standard television practice. The choice depends upon the type of information desired since the radiometer yields quantitative data permitting calculation of apparent, and in some cases, actual temperature; while the scanning and recording process yields a picture indicating the general distribution of radiation but only in a qualitative way since one can not hope to retain the quantitative aspects of scanning throughout the processes of recording, photographing, and printing.

The construction of an infrared scanner involves certain compromises involving resolution, rate of coverage of the ground, and temperature sensitivity. Good resolution requires a short detector time constant and usually results in some reduction of temperature sensitivity.

In the case of the scanner, the motion of the aircraft is such that successive lines are contiguous or overlapping. The resulting information is usually placed line by line on photographic film in approximately the same way that it was scanned. The resulting pictorial presentation is similar in its line detail to that of television. In contrast to television, however, the infrared picture is scanned only once; and the single raster is effectively endless, hence the term strip map. Recording may be accomplished by means of photography of an intensity modulated cathode ray tube trace by direct writing on continuously moving film with a spinning intensity modulated glow tube, or storage of signals on magnetic tape for later processing in the laboratory.

Infrared strip maps, whether printed directly on film or reproduced from tape recorded signals, may exhibit a number of peculiarities not found in photographs. The television type raster resulting from line by line scanning is usually more or less obtrusive, except in good strips made at the higher altitudes; and there are distortions of scale caused by imprecise synchronization with aircraft ground speed and by the angular scanning function. Lack of sharpness and distortion of the grey scale are associated with inadequate electronic bandwidth, and while usually present in the picture to some extent, do not necessarily lead to misinterpretation of the results. One is always faced also with the problem of dynamic range since it is often of interest to record the smallest possible apparent temperature variations and at the same time to preserve a record of the total variation.

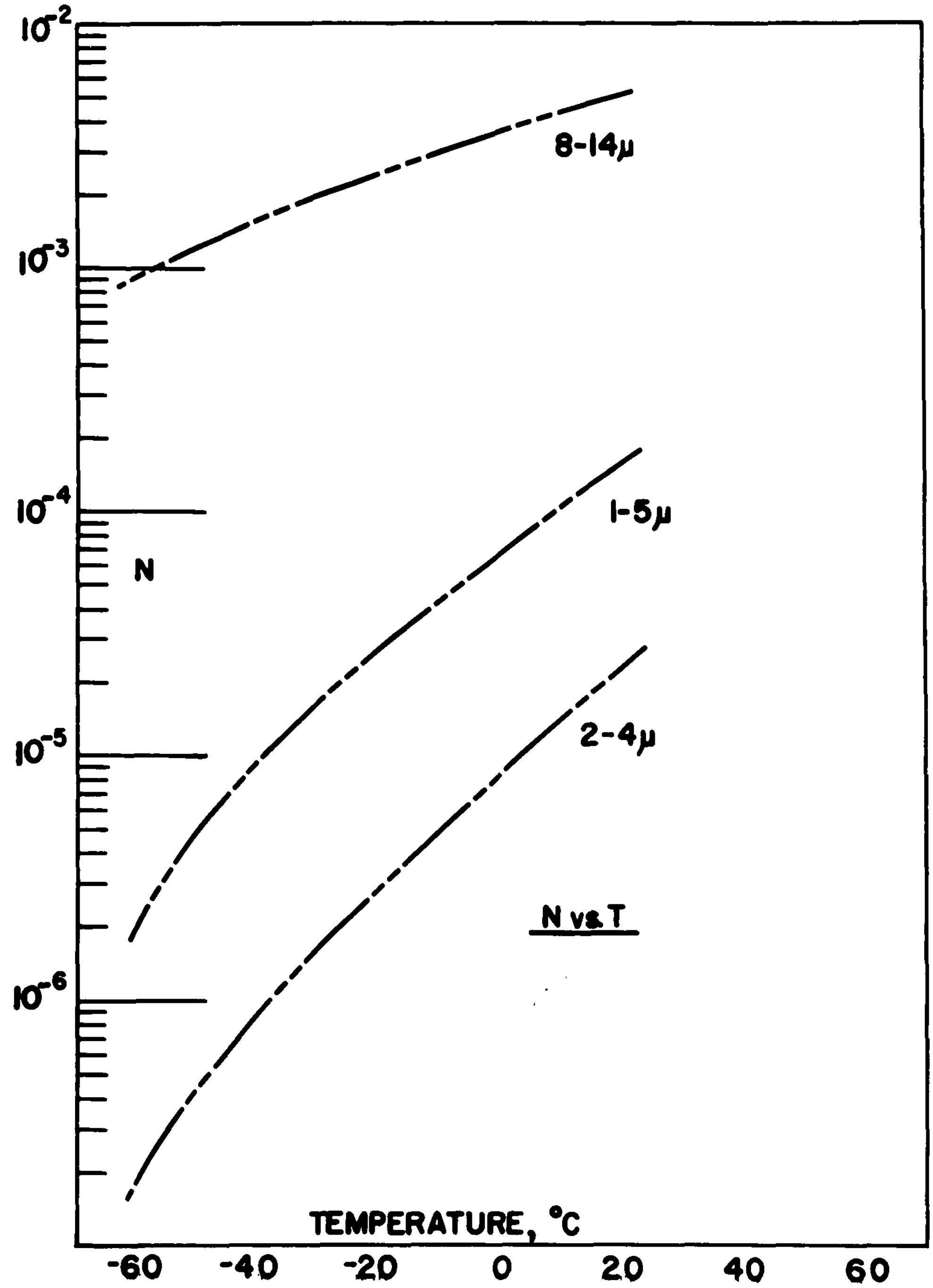
An infrared strip map, although subject to all the above limitations, often looks very much like an aerial photograph; and the tendency to apply photographic interpretation techniques is initially difficult to overcome. A true thermograph may exhibit strong shadows which are really thermal shadows resulting from the relatively low emission of radiation from cooler shaded areas. Hilly terrain scanned in the early morning or late afternoon exhibits strong thermal contrast between sunlit and shaded slopes and often looks very much like a photograph. The grey tones in a true thermograph of natural terrain and water surfaces are related strictly to the product of emissivity and temperature with reflection of the sky or cloud radiation playing a minor role. Even these generalizations must be made with certain reservations because the surface temperature distribution may vary radically in accordance with the local meteorological history. The establishment of interpretation techniques for thermographs is a subject of increasing interest and deserves considerable theoretical and experimental development. Interpretation of infrared imagery is further complicated by the large and increasing variety of detectors, filters, and picture improving

techniques on the current scene. Theoretical prediction of scanner imagery as influenced by the equipment and the environment in which it is operated should help to reduce the amount of actual field data which must otherwise be collected for analysis and guidance of further advancement.

Consideration of scanner performance always involves the question of available energy and the magnitude of fluctuation of the incoming energy. The most important consideration is that of the difference in radiated energy associated with small temperature differences.

Figure 5 shows the radiant energy available in each of three spectral regions as a function of temperature. The spectral regions have been chosen rather arbitrarily, but they agree roughly with regions of good transmission and with the sensitivity curves of available detectors. No corrections have been made for atmospheric attenuation. Because the peak of the blackbody curve falls within the 8 - 14 μ interval over the whole range of temperature from $+20^{\circ}$ to -40° Centigrade, the energy varies by less than an order of magnitude while it changes rapidly in the other regions which lie on the positive slope of the blackbody curve. There is more energy available assuming a detector which integrates over the whole 8 - 14 μ region by about 2 orders of magnitude.

Figure 6 shows the amount of change in emitted radiation corresponding to a temperature change of 1° Centigrade for various temperatures and for the same three spectral regions. These curves are of special interest because ΔN is the quantity which determines the magnitude of the scanner output signal corresponding to a small temperature change. The long wavelength detector has an advantage over the others by as much as 2 orders of magnitude in this respect even if we restrict ourselves in the 8 - 14 μ region to an optical bandwidth of only 2 μ to get completely away from the noise producing



10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
N
8-14μ
1-5μ
2-4μ
N vs T
TEMPERATURE, °C
-60
-40
-20
0
20
40
60

FIGURE 5

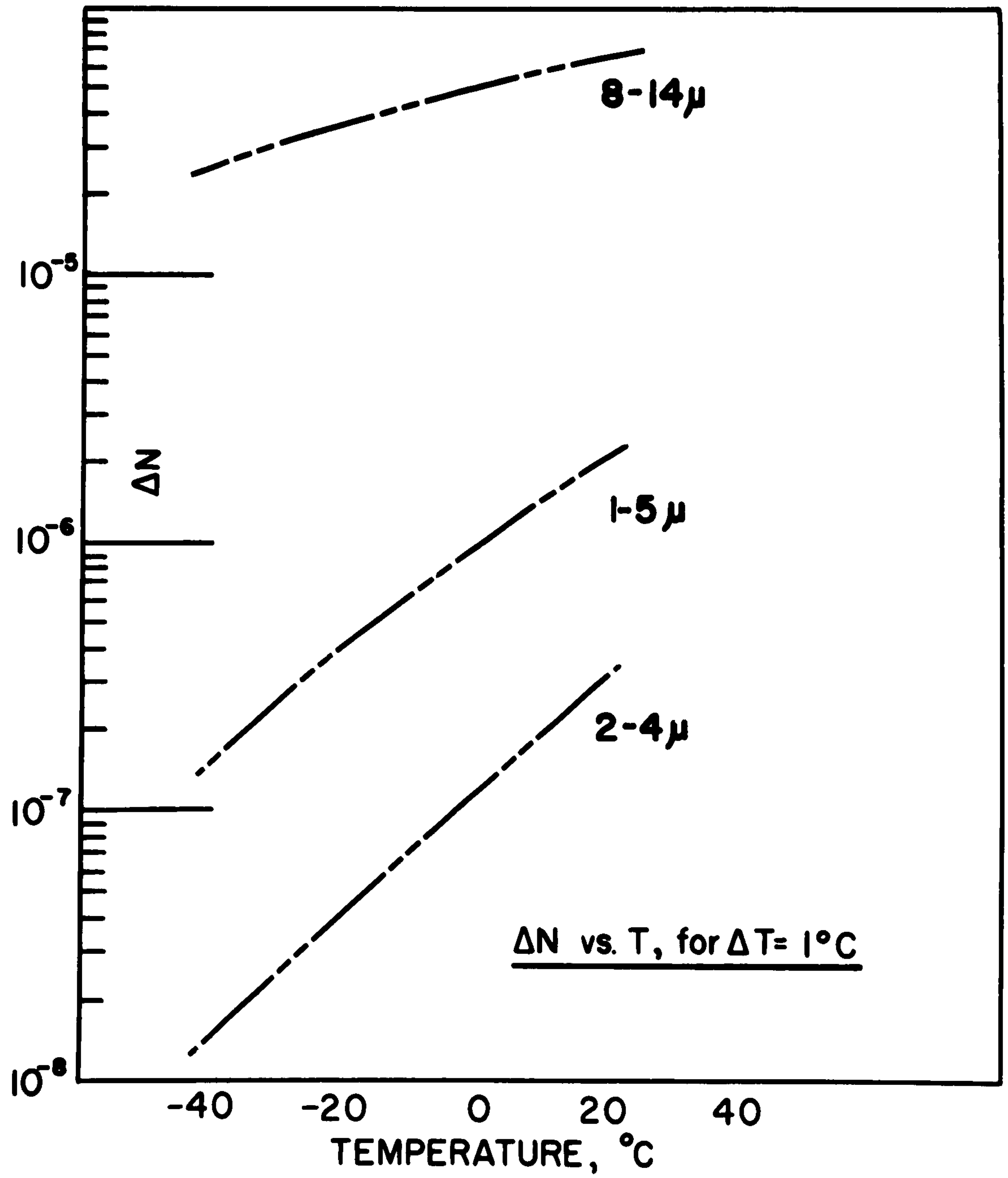

8-14μ
1-5μ
2-4μ
ΔN vs. T, for ΔT= 1°C
ΔN
10^-5
10^-6
10^-7
10^-8
-40
-20
0
20
40
TEMPERATURE, °C

FIGURE 6

marginal regions of the window. For special applications such as detection of crevasses in the arctic or detection of minimum temperature differences in a low temperature environment, scanning in the longer wavelength region is seen to be particularly advantageous.

In summary, it is fair to state that infrared remote sensing techniques are available which permit measurement of radiation fluctuations corresponding to temperature fluctuations of the order of 0.01° Centigrade, and large scale mapping operations yielding qualitative pictorial representation of the distribution of radiation from the surface of the earth, with temperature sensitivity in the latter case of a fraction of a degree and resolution comparable to that of a very early or very mediocre aerial photograph. All of the infrared spectrum for which the atmospheric transmission is reasonably good is now covered. Roughly, quantitative pictorial data may be obtained through simultaneous operation of a scanner and a radiometer using the quantitative radiometric data to key the pictorial representation to actual radiance values. If you make realistic specifications for an airborne scanning radiometer for a particular application specifying only the minimum necessary resolution and temperature sensitivity, the chances are very good that the specifications will lie within the current state-of-the-art.

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AERIAL PHOTOGRAPHY A REAPPRAISAL OF THE TECHNOLOGY

Robert E. Frost

The efforts of Mr. J. O. Morgan and group have been well done in bringing together the many backgrounds, many areas of interest and many concepts for this meeting. I like the general theme of basing discussions on ascending or descending wave numbers or wavelengths or however you wish to express different energy levels or even different spectra. The conference has covered long wave radio thru infrared into the visible. It has been pointed out that other systems utilizing other energy forms may also be useful in gathering information such as gravity meters, magnetometers, etc. Likewise, the sonic spectrum may also yield useful information on the properties of matter. We are all familiar with the contact methods of use of sonic devices for study of elastic properties and/or such things as durability of materials for engineering purposes. In this regard all I can do at the moment is to further emphasize the importance of research in each of these fields. But more important I wish to give Mr. Morgan and his study our organizational support in his task of looking into this rather complex problem.

However, I prefer to look at it from another approach and share with the group our thoughts on this problem. First, I wish to develop the component parts of the BIG PROBLEM which faces the BIG PICTURE and see how they fit together. In doing this I hope to generate thought useful to Mr. Morgan and his study in recommending what might be done. The thoughts expressed about the BIG PROBLEM and its eight component parts will be the subject of a paper at the next March meeting of the SOCIETY OF PHOTOGRAMMETRY.

Before doing this, however, I want to discuss our work, our concepts and philosophies as they have direct bearing on all aspects of the PROBLEM. In doing this you will gain

an insight into what motivates some of us in this business or profession or technical pursuit.. Some of you are aware of what we do and what motivates us in doing it. Some of you are aware of the working arrangements we enjoy with the Institute of Science and Technology in an attempt to do a job for the military to be sure, but also to make a worthwhile contribution to the fund of engineering and scientific knowledge.

It has been apparent from what has been said in some of the remarks and comments yesterday and today, that many of you are not aware of the progress which has been made to date in many aspects of this BIG PICTURE. Hence, I am going to review some of this as I know some of this has been little publicized.

Our present effort which is an uninterrupted outgrowth of research started at Purdue University in 1943 (19 years ago) is concerned with the simple job of extracting information from pictures for engineering, scientific and military purposes. Perhaps I should say, seemingly simple, or perhaps I should ask, "Why should it take 19 years to do that?". Maybe it is because we refuse to give up, maybe we see a real challenge, a chance to make a contribution. A more complete mission statement might be that: "We are concerned with the utilization of any device and its attendant display capable of yielding information about terrestrial and extra terrestrial surfaces when used either singly or in multiple combination for engineering, scientific and military purposes". Said another way: "We are concerned with (1) basic fundamentals of matter-energy relationships and image creation under any condition of environmental stress, (2) methods of extracting information, (3) limitations and reliability of systems and methods and, (4) determination of use for engineering, scientific and military purposes". ("The Program of Multiband Sensing Research at USA Snow, Ice and Permafrost Research Establishment, PHOTOGRAMMETRIC ENGINEERING, December 1960.")

Why are we interested in this, why such a broad perspective? The answer lies in the simple statement of fact, "We are not satisfied with any one, not one, of the many aspects of the BIG PICTURE. To be sure, we can do a good job of conducting a fairly complete terrain analysis of any area even to sociological implications, etc. But, how much more can be done if we really looked at all aspects of the PROBLEM more intelligently?

Our laboratory, as pointed out, is rather unique in Government circles in mission, scope, perspective, composition and outlook. Basically, the laboratory is a collection of three areas of interest. We subscribe to and practice an inter-disciplinary approach in all we do. It was realized long ago that no one person can presume to possess sufficient knowledge to allow him to understand fundamentals and basic relations between matter/energy and image creation and then apply these to all fields of endeavor in the earth sciences as well as engineering with the same degree of skill. Hence a three part organization was formed representing earth sciences, physical sciences and engineering. Methods of doing research are unique also because of the concentrated effort to find out what the sensor saw and determine conditions present so that images could be properly evaluated. Thus, our methods include establishing field study areas in various environments for purposes of conducting coordinated air-ground research.

In doing this we joined hands with the Infrared Laboratory and we jointly conduct several coordinated air/ground exercises each year in environments as widely scattered as Yuma Desert to the Greenland Ice Cap.

This concept has clearly demonstrated its value and use in application to some important research programs for the Corps of Engineers.

One application has been in connection with Operation COLD DECK, the aerial sensing of cold surfaces, utilizing multiple sensing with conventional photography and infrared

scanners. Research performed in the heavy snow/ice areas of the Upper Peninsula of Michigan has found application in the severe environments often associated with Northern Greenland (crevasse detection, ice cap studies, sea ice studies, terrain analysis, etc.). Another important study, at the opposite end of the environmental scale, is that concerned with Operation HOT DECK--the aerial sensing of hot surfaces. Utilizing the same equipment and coordinated air (University of Michigan Infrared Laboratory) and ground (USA CREEL) sampling procedures the study was concerned with surfaces heated by natural means. For example, coordinated air/ground studies were conducted in desert areas (Yuma Desert) in which the external solar radiation provides the source of heat, in Utah in areas heated by oxidation of ore bodies, in Yellowstone Park in areas heated by magmatic and attendant hydrothermal activity and in Theodore Roosevelt National Memorial Park where heat is the result of burning lignite beds.

Another interesting application of the already learned techniques is in utilization of satellite photography for sea ice studies and ice/cloud image separation. This is a very promising area of aerial sensing research and the laboratory is quite confident of the valuable potential such images may have. The future calls for other studies equally important and interesting. Some of these are thermal sensing of volcanic buildup, stream pollution studies, Nimbus satellite photo studies, use of sonic spectrum, atmospheric sampling, use of more "exotic" sensors now in "breadboard" stage. Thus it can be seen that by having such diverse interests, working closely with systems, aircraft, engineers, physical scientists, military men, earth scientists, having academic interests, and always thirsting for knowledge we have found the motivation.

Now let us look at the BIG PICTURE and say "What is the BIG PROBLEM?"

There are eight component parts and they are related to or they form eight areas of interest.

The PROBLEM is one of looking into each of the eight areas for the following:

1. Determine what has been done in each area of interest and assess its value.

2. Determine needs in each area.

3. Determine extent of interdependency between each field.

4. Find out why there is little or no balance between various efforts solving the PROBLEM is contingent on intelligent study and answer to each of these items and determine or establish good balance between all component parts.

The following is offered not as a complete analysis of the problem, but to toss out ideas, stimulate interest, provoke thought and invite comment.

1. Basic Phenomena--the relation between matter, energy and image creation. Much has been done to date by the research scientist and many technical papers have been published on some of the findings. However, much of this has been from a pure scientific standpoint in which the scientist was undoubtedly motivated by the thirst for knowledge--not knowing or particularly caring about a specific end point or application. This picture has changed markedly during the past few years and much scientific research has been and is being done based on problems--oriented motivation as a problem specifically relates to aerial sensing.

Why is this important? To put it bluntly, it certainly should be sound thinking to subscribe to the philosophy that it would be ideal to design equipment and then use it to suit specific needs in instances where consideration for the design and use reflects knowledge of basic matter--energy relationships and further with respect to the type and amount of information desired. For example, to record earth surface features utilizing visible light,

why not use the conventional camera, a suitable film/filter/optical system and utilize weather conditions desired to give the best image characteristics? There is NO known equipment which will surpass this to date. We now have a variety of systems which go on beyond the visible portion of the spectrum. This does not make the camera obsolete. It merely adds to the package of sensors available to give information. It, therefore, behooves us to determine when and under what conditions these other systems can be used. We have used the aerial camera so long that we have developed an intuitive know how on its proper use. We must now give thought to extent of use to the newer and more sophisticated systems.

To record differences in energy which are thermally engendered and are either reflected, radiated or emitted beyond the visible, it is necessary to select a sensor package designed to work in certain energy bands, but with all due consideration for the fundamentals involved and the atmospheric conditions through which the energy must travel. When used improperly, such devices vary from worthless to merely providing a novel way to take a conventional picture at great cost. More serious, however, is the fact that often it is not that there is no information, but that a case of untruths has been built up around error and misleading information. The same can be said of long wave radio pictures. Success is based on cognizance of design features, limitations, natural and instrumental parameters and intelligent use.

2. Sensor Systems and their carriers and factors limiting their use. This is a very difficult subject to cover. First, everything related to this aspect is costly. One question which is logically raised is: "Do needs exist to marry aerial sensing equipment and the carrier?" In the past this has not been a major item for conventional photography. However, as new systems have become available and the desire to use multiple imagery devices has come into being, it seems that the problem has become quite complex and costly

resulting in confusion and disappointment reigning supreme. Modification of an aircraft is very costly--particularly if a system is heavy, bulky, has unusual power requirements, requires extraports, or requires a complex crew and operating procedure. Likewise, much of the sensing equipment is notoriously complex and often tempermental causing costs to soar "spaceward". Certainly, this area needs thorough exploitation by manufacturers of aircraft and the components of aerial sensor systems with full knowledge of basic fundamentals and end use.

3. Methods and equipment for obtaining information from images. It is in this category that much progress has been made. Perhaps this is because purchase of the final print is inexpensive does not mean that extracting information is easily accomplished. Here is an area suffering from personal and professional problems. It really does not matter whether the study of photos is called an Art, a Science, Photoreading, Photo Analysis, Photo Interpretation, Remote Sensing, Multiband Sensing, Terranology. Each user is after information and what title is given to the pursuit is pretty much a function of the method, the approach, and the intellectual ability. There is much merit in all approaches and methods, however, in this as in other component parts of the BIG PICTURE more research needs to be done. Why not really exploit some of the methods and determine what degree of dependency might exist between several in order that more useful and more reliable information can be obtained from the various types.

Another important and timely aspect of the problem is that pertaining to automatic data processing, scanning retrieving, storage and computer oriented study. Often, the excessive number of pictures obtained for study is so great that a disproportionate amount of effort must be expended for information gained. Along with this is the ever present need to establish and maintain collections of images of natural and cultural

objects or surface features, particularly the type showing how an object or situation looks throughout the spectrum. Above all, the efficient and intelligent use of man and machine must be based upon the job requirements, limitations of man, limitations of machine and the degree to which one may or may not supplement the activity of the other.

4. The Uses of Aerial Imagery for Engineering, Scientific and Military Purposes. Perhaps more work has been done in uses or application of aerial imagery than in any of the other categories or aspects of the BIG PICTURE. For more than 20 years we have enjoyed the fruits of successful use of air photos as applied to many fields. Some papers have reported on research or on concepts of how information is obtained. A limited few have been of a philosophical nature and some have been on method and on instruction. But, for the most part, the bulk of published matter has been concerned with application to a problem and in doing so covered the earth sciences, engineering and military aspects.

During this period of activity the use of air photos for professional and industrial purposes has "grown like Topsy". Research has been performed on development of a system or method primarily from an engineering standpoint only to find application to one of the earth science fields. Of course, there have been almost cataclysmic causes for the rebirth or rediscovery of the camera such as war and the inquisitive nature of intelligence personnel, the desire to explore other lands for development and rehabilitation and the Inter-State Highway System.

It is perhaps now necessary to re-evaluate what has been done and to see that all important and worthwhile uses have been publicized and are in the technical literature for all to use. Does the technical literature really contain a well balanced series of papers reporting on methods and uses for the various major professional and industrial interests? Papers are needed which point out how and in detail just how each of the various sensor

systems can find application to a specific field in engineering, one of the earth sciences, the military or as a space probe. Need exists for informative papers describing not only what CAN be done, but HOW. These papers should be informative, well written, and present information based on sound engineering and/or sound scientific principles.

In summarizing uses,one aspect of the problem is the shortage of basically informative papers in each of the following and apparent disproportionate balance between the various uses. These are:

(a) Uses for engineering purposes.

(b) Uses for scientific purposes.

(c) Uses for military purposes.

(d) Uses for analysis of extra terrestrial surfaces.

Thus, in each of the above, it is necessary to determine what has been done or extent of progress, what the needs are, and what relationships exist between the various fields of use.

5. Training - Visual Aids, Methods and Personnel Selection. What about the user? This is a very serious part of the problem. In one sense it is basic since the information obtained is only as good as the user was able to produce--not as he intended to produce, but as he accomplished. Just because the analyst owns a stereoscope or has a precision instrument or a "PI Kit" does not imply license to analyze images utilizing many portions of the spectrum from the ultraviolet, through the visible, into the infrared, and on out into long wave radio. It is true that recognition and familiarity with the expression of natural and man made features plays a most important part in image study and description. Hence, it can be said that man is limited by his background, experience, interest and curiosity.

The above is quite true in the visible part of the spectrum. But, being thermally blind and not sensitive to radio frequency response man must learn an entirely new set of standards and values if he is to study thermal and/or radio images. This is only part of the picture. Successful analysis of such exotic pictures is by definition contingent on knowledge of certain basic matter--energy relationships, energy transmission through the atmosphere and image creation. Thus, object recognition may be grossly misleading and techniques based on such are practically worthless. Just how does one get this message across to all who use aerial imagery? Perhaps we need some genetic mutations which result in polarized vision, an antenna in addition to the probiscus, and perhaps phone jack recepticals beneath the ear in order that man can best program the computer.

Another aspect of the problem pertains to formal instruction, the academic classroom, the short course, or the military training program and on-the-job training. The teacher by definition must be informed. He must pursue the literature, he must maintain contact with his colleagues, he must keep abreast of the recent developments and uses and above all, he must have or seek the opportunity to "practice what-he-preaches" through professional and/or private contacts. Classroom instruction needs well made and well chosen visual aids, good equipment, and a good collection of aerial pictures of all types. The combined classroom/laboratory/field trip type program has proven to be very successful. The teacher must inspire as well as teach. The rest is up to the student!

Personnel selection is also very important to the problem. Are we really giving proper attention to determination of desirable personal traits, background and other characteristics? What type of person is really needed for each level of proficiency in each field? These must be looked into if analysis pursuits are to keep pace with equipment development.

This leads to personnel selection. Here, perhaps the human systems engineering, psycho physics and related fields can be of great assistance after such fields have been made aware of what is to be accomplished and what the tools are.

These major items and how they fit together and how they should fit together and what to do about them constitute the BIG PROBLEM which faces the BIG PICTURE.

In summary, I think it is time we all got together. We should sit back and look at our progress and concentrate on real problem areas. Much money is being spent. Is it being spent wisely? My thoughts are that if we look at these eight areas and determine present status, current and future needs, then find ways of establishing and maintaining a good balance between all efforts, then we will do the following:

1. Obtain an excellent cross-section of opinions, facts, methods, ideas, equipment, etc.

2. Technical literature will probably be more widely used.

3. Establish and encourage communication between any and all working on any aspects of aerial imagery.

4. Insure that proper tools developed and best methods of use known.

MULTIBAND SENSING

Robert N. Colwell

[Dr. Colwell's presentation involved the showing of a series of interesting and unique slides to illustrate the applications of multiband sensing to the different earth science fields. Rather than include the text without the illustrations, we would like to recommend an article by Dr. Colwell that appeared in AMERICAN SCIENTIST, Vol. 49, No. 1, March 1961. The title of the article is "Some Practical Applications of Multiband Spectral Reconnaissance." The general context of Dr. Colwell's talk is included in this article along with illustrations that include prints of many of the slides that were shown at the symposium.]

AIR FORCE REMOTE SENSING PROGRAMS

Carlton Molineux

Our primary mission is investigating the surface of the earth and its capability to support aircraft operations. Secondly, the more basic mission is to enlarge the general knowledge of remote areas that may be denied to us, which we can fly over with suitably instrumented sensor aircraft. As you know the process of field investigations, particularly in the arctic regions which we have been interested in for a long time, is pretty slow. You can't get to many areas at one time. It takes you a long time to determine the parameters that you need to know in any detail and to evaluate these as to the suitability of the ground for such things as emergency airstrips of minimum length and the feasibility of using these areas for later installation development. Our approach is just about what Bob has indicated; the evaluation of suitable sensors and their development, exploitation, and use in a flying terrain analysis laboratory as we call it. This happens to be a ski-equipped C-130 aircraft. Once we have gotten the data, we evaluate it for the aims which we have. I'll give you a little list here of some of the properties which we need to know for the purpose of picking out the areas for aircraft to land in. There are naturally the surface topography; the micro-relief; the roughness (that's the prime importance if you are going to land an aircraft); the composition; mineralogical and chemical; availability of construction material (gravel, sand, clay) and its texture, grain size, density distribution, and degree of compactness; the geologic structure itself; the hardness; bearing strength (that is probably a close second in our requirements for airstrips); the moisture content; ground water table; the evidence of permafrost and its depth; water supply; temperature; albedo of the surface (this is quite important to us because during certain seasons of the year in the arctic,

especially at the melt season, you will louse up an air strip that you could possibly use for two or three weeks due to the surface run off from the melt.); vegetation (color, reflectivity); geologic parameters, rock discontinuity, thickness, stratification, evidences of underground discontinuities; and then lastly the natural force fields that might be there--gravity, seismic, and magnetic.

Our program at present includes Project SATAN. It stands for sensors for airborne terrain analysis and it comprises a thorough study of all types of feasible sensors and their suitability and their limitations in this sensor aircraft we have in mind. It covers such things as the limitations of air speed, altitude, weather conditions, possible interference of multi-sensors used at the same time, the limitations of the topography, shading which you might run into, the vegetation cover, topographic conditions, and again the local meteorological and climatic conditions you find in the area. So far this has turned up about 23 promising sensors and we are going under a sort of matrix system as to the applicability of these sensors either singly or in combination with these parameters I mentioned--topography, climatic conditions, and the like. It is surprising that a lot of these sensors may have been developed initially for other uses. Of course, some of them could be modified and used for our own quite narrow purposes.

The second effort that we are supporting is the work going on right here at Michigan under the sponsorship of Walter Bailey at ONR. I don't think I need to say anymore about that.

The third major thing we have is with the Waterways Experiment Station of the Corps of Engineers at Vicksburg. They and we are jointly funding a program which is being run by Texas Instrument. It is a theoretical and experimental study to develop a catalog of radar and infrared returns of known soil conditions. Dr. Colwell just showed

you the last couple of slides indicating the optimum output for that sort of thing. We are contributing to the radar investigations. TI has picked a radar with a four band coverage, a modification for this one set will get you a four band coverage--C, K_a, X, and P bands. We will be able to get different penetrations into the terrain sample. This is going to be hung in a 50 foot arch building and suitable soil sample carts made available of enough size to get away from edge effects, depth effects, and the like. Radar measurements will be taken on known controlled soil conditions--such things as grain size, amount of compaction, moisture content, thickness. So with the different penetrations, we will be able to tell, we hope, what these soil properties are. This will be done simultaneously with the infrared measurements which Vicksburg is also doing on the same samples. It will help to hook them up with a catalog of identification of these properties; and the next step as you will see is to apply this on a helicopter scale over known areas, and then lastly to the reconnaissance of remote areas.

We are fairly active in the photogrammetric research. I was quite interested in Dr. Colwell's showing of the camouflage detection film, because one of the things that troubles us is micro-relief--the roughness. Now I hope that I don't shake you, but we would like to know this surface roughness to 6 inches. Now this sounds kind of academic maybe; but when you are going to land an aircraft on a remote area unimproved, this is important. So we have a contract to study this. The people tell us that they think with camouflage detection film and all types of film-filter combinations and with, as they described it, a tunable filter--one which you can rapidly change over the same film, they hope--we can get measurements of surface roughness to this 6 inch standard which we optimistically hope for. We are also considering the use of spectral photometers and the like to do this. This is apart from the terrain general description so forth; this is specifically for the surface roughness. We have in-house work going on with several photo interpreters, photo

geologists types. This terrain description has been done very successfully for us in the past from photogeologic interpretation of arctic areas. We have picked a great number of sites on the whole perimeter of North Greenland that seem feasible for aircraft operations. We have gone to a lot of these sites and proven this with detailed reconnaissance on the ground; test pits, strength measurements, moisture content, the whole gamut, and climaxed this with landings of heavy aircraft on strictly unimproved sites that had been selected in this way. We have landed heavy aircraft such as C-124's and C-130's on this sort of thing. This is quite a going thing in our shop.

Fairly recently, we have come across a Canadian exploration geophysicist who has a method of propagating pulsed radio frequency energy into the ground. He calls it the input system; induced-pulsed transients. As we heard yesterday, we are getting reradiation and the dielectric constant and the conductivity of the subsurface and near surface layers is measureable. This fellow, under the sponsorship of the Canadian agencies, has done some work in the White Sands natural monument Arizona and the likes for water table and moisture content determinations. This equipment is truck borne. We have him starting on some work of extrapolating this to airborne reconnaissance for our purposes of soil moisture content which again is quite important to us for the way in which it contributes to the strength of all natural ground. We have also in the past, and still are, developing airdroppable devices. This is something that hasn't been mentioned here in the last couple of days; I will just do it right now. We have developed devices which you can drop from aircraft to indicate the ground hardness. It is a simple gadget consisting of a conical tipped cylinder with a suitable indicator which is actually a decelerometer. It hits the ground and the resistance to penetration of the ground or the hardness will trigger off the indicator. It could be almost any type--flares were our earliest one. It is a go or no-go type of thing.

If the ground is harder than your preset value of the indicator, then it triggers off your indicator; and by sprinkling a string of these along the airstrip site that you are exploring, you are getting, on a statistical basis, a go or no-go capability of ground hardness. Secondly, we have developed in the past a droppable seismometer for measuring ice thickness. This operates on the seismic principal. There is a coupling effect between the airwave and the icewave. You drop the seismometer on the ice with a telemetering gadget in it and drop a small bomb on the ice of the same floe and within the same general area. The seismometer records the shock wave and transmits back your entire wave train. In this wave train, this coupling effect shows up. There is a constant frequency train culminating in the pulse. This frequency is inversely proportional to the ice thickness. This has worked out quite nicely with us. The only problem is that you have to cart around a dropping mechanism and a bomb, but these are techniques that are available for airborne reconnaissance of terrain properties.

We have also sponsored some research in the past using pulsed radar for getting ice thickness. This works in fresh water ice. The saline ice has a great lack of defined difference between the bottom of the ice and the water. It turns into mush and it is a gradual process; but in fresh water ice you get quite an interface, and we feel that radar is a good method for getting the ice thickness in fresh water ice such as lakes, glaciers, and the ice islands which incidentally are fresh water ice.

Now we come to the question of how to accomplish this. We have assigned to us, in our laboratory, the ski-equipped C-130 long range reconnaissance aircraft, and we are in the process of instrumenting this right now as a flying sensor vehicle. The optimum altitude for efficiency of use of this bird is about 25,000 to 30,000 feet. We know that is asking a lot of sensors to operate at this altitude; but we estimate that by suitable high level flights like this, we can either pick out feasible areas or eliminate them. Then we

can come down low for passes with our sensors that work at lower altitudes best and get detailed reconnaissance of these particular areas which are of interest to us. Our present instrumentation includes several gravimeters. We have a Lacoste-Romberg airborne gravimeter and a modified Graf gravimeter. We have a total component magnetometer and an up and down sensing pyranometer for getting the albedo of surface and clouds. Photographic equipment is pretty standard--KC1 and T11 cameras for vertical and oblique photography. It doesn't do us much good to get sensor data unless we know where we are, so we have quite a list of very precise navigation equipment--astro-trackers, doppler radar, vertical reference indicator, driftmeters, airborne profile recorders, and the like. Later we hope to come up with terrain analysis radar such as Texas Instruments is developing and such things as side looking radar and infrared scanners. A lot of these are classified, of course, but with us there shouldn't be any problem in getting them on board and using them. We hope that after this instrumentation we will be able to cover any remote area of the world with multiple sensors: photographic, radar, infrared, pulsed radio, and what have you, and fill in a lot of data that isn't known about remote areas and also boost our capability for determining their suitability for Air Force operations.

Mike Holter: Do you have any observations over the sea?

Carl Molineux: We probably will. Sea ice is important to us. Obviously if you can land on sea ice, this gives you another capability for emergencies or support work.

MOONLIGHT PHOTOGRAPHY

Yale Katz

At lunch yesterday I happened to sit at the table with Joe, and I told him that we had some pictures that we thought would be of interest to this group. Now I don't have any slides, but I believe that the pictures I have will be of interest. This first picture shows a 1956 Dodge station wagon, two tone with exhaust running and shadows underneath. You can see sky in the background and trees. Now the question that you normally ask people is, at what time of year and what time of day was this photograph taken? Then you have a contest and those that guessed the closest win a prize. So far I haven't lost a bet yet. This photograph happens to have been taken at midnight. It was taken on 18 November 1956 with no artificial lights except headlights on the highway in the background. I submit this photograph for your inspection at a later time. If you are very observant, you will see the streaks in the sky background which are star tracks. This happens to be very standard photography. It was taken with a tripod at about 1 minute exposure at equivalent f4.5 on a not very fast film. What I am trying to say here is that there are a lot of things that can be maximized with equipment at hand without going into exotic types of equipment. I think we can make improvements of an order of magnitude by maximizing such items as lens aperature and film speeds and by careful handling in the darkroom. This second photograph of rather low quality is an aerial photograph. This photograph, however, was taken at midnight in 1956 right around the period of a full moon, altitude of 5000 ft., Tri-X film with a 35 mm camera. The exposure was f1.5 at three seconds. Image motion compensation was utilized. You

will note that you can see houses and barns and roads and snow on the fields, etc. This photograph was taken over an area near Wright Field, Ohio.

This next photograph was taken in the Boston area. I had a photographer who was willing to climb a 125 foot bridge and sit perched on top of this thing around midnight in June of 1957. He sat up there with a Speed Graphic camera and produced this picture. This picture also was taken during full moon time and I had a low light level photometer with me, and I measured an illumination of .013 foot candles averaged over the small area that the camera was looking at. This is equivalent to the full moon at zenith. You can see much detail in this picture. The sign that says speed limit 15 miles per hour could not be read at a short distance away. This picture was taken at an equivalent exposure of f1 at one second. This means that the photographer actually held for a little longer than one second, and it was taken on film that was not particularly fast. No special techniques or gadgets were used. Now here is another picture of the same scene taken after messing around in the darkroom with the same negative. Intensification techniques were used and you are bringing out some more detail that is inherent in the scene without having to go through any special spectral ranging and so on. This is another picture that makes everything look like daylight. You bring out railroad tracks and other objects.

Now there is one thing that you can't do in the government and that is ask for a little increase in what I like to call GFI--government furnished illumination. You have to go along with what you have here. You can't ask for an increase in the albedo of the moon. This is given to us as a certain percent and we kind of have to stick with it.

You may ask why we like to take night photography with available illumination instead of using flash techniques. A lot of this work that was done five years ago, and not

much has been done since I regret to say, stems from the fact that during the Korean conflict much of the Chinese Communist movements were made during nighttime. We had no nighttime reconnaissance capability other than flash-bomb techniques. In flash-bomb reconnaissance you set off a flash-bomb here, and another one here, and another here, and then you get shot down over there. It is a very good tracking device, so we did not do very much of this. If at that time we had had a nighttime capability comparable to that shown by these photographs, I have the feeling that the enemy would not have been able to have moved so freely.

Now there has been a lot of talk about resolution--I hear resolution bandied about and I have here a set of enlargements of a small section of a negative that was taken over Boston. I showed this to a pretty secretary we have in Santa Monica and she said, "I don't know what this is". I said, "This is an aerial photograph of the ocean"; and she said, "Oh, that's that Santa Monica Beach", because that is what it meant to her you know. She is on the beach all the time when she can. Then I showed this to an astronomer on our staff and he said, "I can't tell you what it is, but you tell me that it is an aerial photograph and it looks like the granulation on the sun's surface", which you would kind of expect from an astronomer perhaps. If you showed this to a psychologist, I hazzard to guess what you might expect for an answer. This happens to be a picture that has been degraded to an equivalent ground resolution of 400 feet.

This next picture shows the same presentation taken with 200 feet resolution. You may notice how things begin to look better, especially when you look back at the 400 feet resolution picture. You also begin to see what happens to the grey scale when photographs are degraded in resolution. You don't see much contrast from the black to the white.

Contrast degradation is effected by resolution.

The next photograph is the same area and shows 100 feet ground resolution patch. You begin to see some patterns. You begin to see street patterns which you had never seen before.

The next series of photographs show ground resolution of 50 feet, 25 feet, 10 feet and 5 feet. The 5 feet resolution photograph shows Fenway Park the baseball field in Boston. It shows the parking lot in back. You also can see the parking strips which are about 6 inches wide. This picture was taken from 100,000 feet altitude under a very fine atmospheric conditions; I might add, the scintillation effects and turbulent effects were pretty much nil. We approach such resolution as 100 lines per millimeter film-lens combination. Anyway what we are showing here is how the imagery degrades as you get down to resolution of about 100 feet. Such things as the bridge and Charles River degrade, and you begin to lose them as you get down to 100 feet resolution. At 200 feet it's gone and at 400 feet you don't know what you are looking at anyway. So I kind of raised the question without answering anything as to what happens to stereo as you degrade resolution.

Recall the USSR moon shots that were taken by satellite. We did some analysis on these back at Rand a couple of years ago and the best figures that we came out with by comparing different techniques was that the resolution on these pictures was something like 8 - 40 miles roughly. Now some of the best pictures that you have seen of the moon have been taken with the 200 inch Polomar telescope or some of those that may have been taken at Pic du Midi in France. The resolution on these is of the order of 1 mile. Tiros photography gives you a resolution of about 3 miles looking straight down with a wide angle camera. The narrow angle camera which gives you a limited field of view is about a

factor of 10 better than that. That is 3 miles or 15,000 feet. The picture I showed was 400 feet ground resolution. Of course, in Tiros, we are looking for clouds and that makes it much nicer. This is just to give you a little perspective.

Well the question is, can we do a lot of this stuff in the satellite? I would submit that if we can get this type of photography (5 feet resolution from 20 miles altitude) that I can take something up to 100 or 200 miles altitude and resolve about 15 or 20 feet. Under the most optimum conditions. I am really not talking about a "spit-back" type of satellite. I am talking about a retrievable capsule. Certainly telemetering has its disadvantages. I think with that I will drop it.

Joe Morgan: What do you know about television with a very low light level capability?

Yale Katz: I haven't been in touch with this thing now for the last couple of years, but at Wright Field the Air Force has had this under development for a long time--very high image intensification techniques.

Joe Morgan: It hadn't occurred to me until Walter Bailey mentioned it that we have kind of ignored the possibility that it might be a useful item in this area.

Yale Katz: What we are really saying here is that a lot of the world is denied to us either by virtue of geographical location, the time of year, or because it is nighttime. Now with photography you have two limitations--one is cloudiness and the other is darkness. We are trying to show here that darkness need not be a limitation. If one wanted to do some type of climatological study, for instance, I think that he could prove that cloudiness is less of a factor at night than it is during the daytime for the most part--not necessarily in certain regions because there are certain regions that would disprove this.

But for a general case, there is less cloudiness during the nighttime than during the daytime primarily because of convective effects which are not present during the nighttime. What we are really saying here in effect again is that we are opening up a large area for nighttime operation and the operation is very passive.

Gwynn Suits: In regards to natural science applications, is there anything that can be done with moonlight photography that could not be done better later during periods of sunlight?

Yale Katz: Well to begin with for areas above 66 $1/2^{0}$ north, you are not going to be up there to see anything during half the year anyway; but I would also submit that for very low grazing angles right around sunset time, you can do an awful lot of PI work on ice surfaces and snow surfaces by shadow effects. These effects are fantastically good. I won't tell you any particular application I have in mind; again, I will leave it up to you.

Mike Holter: Did you get the low resolution shots by defocusing a projector?

Yale Katz: Yes

Mike Holter: I would like to make a comment on this subject. First with regard to trying to predict what a line scan of poor resolution will do. In some cases, simulations produced by defocusing may not give the correct answer. We have built a resolution degrader that is a line scanner. In some cases, not in all cases, the effects are different.

Yale Katz: I am sure they are.

Laurence Lattman: In geologic work we have been able, in some cases, to delineate drainage patterns more rapidly by knocking down or degrading the resolution and thus preventing the human eye from being confused by detail. It can then scan more readily. Controlled resolution, I believe, has a place provided--you start with a sharp presentation and

work down and can always get back to the sharp presentation if you have to.

THE HISTORY OF RADAR GEOLOGY

Bernard Scheps

My first few remarks will be to give you a background on radar geology and how we got there. I think we owe a lot to a fellow by the name of H. P. Smith who in '47 was parked on the ice cap in Greenland as a Lieutenant in the Army Air Force. He noticed that these radar pictures looked pretty good. He sort of bet that you could make a map from them and he did; as a matter of fact, he developed the whole theory of radar mapping himself being completely unaware that anybody had ever done anything in this field. He made a map of the northwestern coast of Greenland which turned out to be an order of magnitude more accurate than the aeronautical charts of the area. Consequently, the Chart Service map had to be revised. Smith then wrote a rather thick classified report on the subject. He pointed out to the high command that this was a powerful tool and maybe somebody could do something with it someday. Well the high command didn't believe him since he had insulted and mortally wounded the Chart Service which was unheard of. So they turned over H. P. Smith's stuff to the Geological Survey. H. P. stands for hot pilot; and incidentally, he is probably going to be a brigadier very shortly.

The U. S. Geological Survey agreed that there was something of value in the idea of radar mapping. We used his methods and constructed maps without previous knowledge of what the area might be. We made maps of Denver, Birmingham, Philadelphia, and Harrisburg. By the way these were made from World War II PPI radars.

Along about 1955 or 1956 when the Antarctic work was picking up again, we discovered that in 1947 or 1949 an Ensign Reynolds had flown a lot of radar photography down in Antarctica. This again was World War II PPI radar. Reynolds had even mentioned on his

log that he had done some radar mapping and that was heresy because he was flying tri-metragon photography at the same time. However, the tri-metragon photography didn't look through the whiteouts or look through the clouds and stuff like that.

We used some of that stuff and we made some maps of portions of Antarctica that had never been mapped before. We made some controlled solutions to help the tri-metragon out. We also had some very notable flops, but there is at least one published map that has a coast line that comes entirely from radar; and there could be several other published maps if they ever got around to incorporating these data.

We were able to do something that you might even call crude glaciology. We could pick out strains and stresses in the ice, the crevassed areas, and areas where there were probably seracs. We could certainly pick out the shelf ice and the land ice and distinguish between them and get the major floes and major glaciers. This comes under the title of a project named TERAIN. It is classified work unfortunately, but the code name is TERAIN--terrain radar interpretation.

I like to think of the work of Dr. Siegel here at the University of Michigan as being the first real radar geology. Dr. Siegel is the one who first bounced different frequencies of radar off the moon and by comparing the response of the different frequencies came up with some estimates of the composition and roughness of the moon surface. The Russians seem to take exception to his conclusions, but they don't take exception to his methods. There has been a little interchange on that. That was in 1958 or 1959, I believe, that Siegel did his work.

There has been some work by Allen Feder at various places. Fedder is a vigorous and staunch supporter of the idea that you can get geology from radar. He has been working from about 1959 until about the present time. I guess you could call him the

White Knight. He rides out to tilt with anybody on this subject.

Bob Frost has done work on the snow and ice fields. I guess you could call it glaciology rather than geology.

Goodyear Aircraft has done a tremendous amount of work in radar terrain return. A lot of it is very classified, but a lot of it is not so classified. They have worked for the Air Force and for the Navy and for the Corps of Engineers.

More recently Bill Fischer was drawn into the net by myself. I gave him some photos with never so much as a word about what they really were; and he did some very useful geologic interpretation from them, and you will hear more about that later.

There have been others. Autometrics Corporation has done some work in connection with Air Force projects. The Engineeri Research and Development Laboratory, Mine Detection Branch has examined soils with and without mines wet and dry, etc. I have probably neglected some other contributors to the field, but essentially that is it.

It is really amazing that since 1949, nobody has really grabbed the ball and run with it. Over and over again in each one of these projects, a very real capability has been demonstrated. Certainly when you come to such situations as that in Antarctica where the cost and risk of flying in the area is very great, the tremendous area coverage to be gained from radar is a distinct advantage. Even with all the evils that there may be in radar, it is the only one that gets through weather and gives you an all-weather capability; and there are parts of this world that always have cloud cover. It is not just Antarctica, it is places like Central America, parts of which have never been successfully mapped with aerial photography.

So, this is how we arrive at the present scene. This is essentially the history of radar in geology. It might be well at this time to introduce some of the geological work

done by Goodyear Aircraft Company and Bill Fischer. Now Goodyear went ahead and they said a lot of this stuff looks like it has got a lot of geologic information in it. Possibly a geologist could make better maps than the ordinary mapping type of person. So Goodyear Aircraft Company hired a geologist and ran him through a couple of weeks of what radar is, how it works, what errors are inherent in it--the kind of thing you might teach a moderately intelligent man in several weeks. The man was a competent geologist, had done field work and photogeology; and he rose to the challenge magnificently. Goodyear gave the geologist an area on the Kentucky-Tennessee border. They checked first to make sure that the guy had never been there; and they found out, as a matter of fact, that he had never left the state of Arizona so he was a safe candidate for the job. From the radar photographs, he constructed a map and wrote about a ten page report on the area. He judged by the streams, by the slope, and by the agricultural pursuits that he saw there what the nature of the soil might be and what the nature of the underlying strata might be. Now he represented a number of faulting planes on his map. [Illustration of the radar geology interpretations were shown.] You can look along the streams and in many cases see why he determined that there had been facturing and faulting there. He concluded from this that the underlying stratum must be limestone. Then they checked his information against the existing geological maps of the area and found out that the guy was awfully right in many things. His estimate of the rainfall was a little shy; he didn't realize that the area was quite as humid as it was; his estimate of soil thickness was quite good, but the cutoff for his zones were somewhat displaced. In orther words, he couldn't accurately place the contact zones. However, in general, it was a very competent job of photogeology. Now this is a humid area; and they said, okay, sure, you have got all kinds of clues--streams and farming and stuff. Let's give you an area that is arid. So for the next sample, they took him to a portion of southeast Arizona

where he had never been before or where he had never done any work; and he came up with this [second illustration, not included] which merely breaks out the crystalline rocks, the volcanics, and the sedimentary deposits and gives some indication to the fact that it is arid by the stream pattern, the washes, the irrigation patterns, and so on. But it was certainly a lot less detailed than the humid area geology was. There are far less clues to the underlying strata and underlying structure in this particular arid area. He did a few others, but I believe that these serve to illustrate the approach to the problem.

What he did was very successful, but it certainly leaves a very strong impression that there is a lot more to be done. He also worked in the context of military terrain intelligence in an area on both sides of the Mogollon rim, and he was able to find such things as gravel and sand deposits where you could get your construction materials. He was able to say, here is a mesa where you will have excellent terrain observation capability. Cross-country movement will be difficult here across this badly dissected area whereas it will be comparatively easy over here, and so on.

Now at the same time that this was going on at Goodyear, I devised a really sticky double-play type of thing. I gave Bill Fischer some of the same photography, and I didn't tell him a thing about it. I just said, here are some radar photographs. Do you think you can get something out of them? I didn't tell him how radar worked, I didn't tell him what set it was, or any of its characteristics. It looked pretty good though. As a matter of fact, it looked deceptively nice. Well, Bill came back a couple of months later and he wanted more. He though this was wonderful stuff and he thought that it had great possibilities and he had done some real work with it. He wrote a couple of informal letters on his work and I will let him talk more about that later. I think it is very significant that Bill knew nothing about radar at all when he did this work. After we go home now, I can start telling him things about it.

Now there began to appear a problem of semantics between Bill Fischer's work and Goodyear's work. Bill Fischer might say granite and sedimentary rocks have characteristics that give different radar returns. Goodyear would say materials that are so alike in their chemical composition couldn't possibly have a very different radar return. They are both right. Actually both materials are very comparable; and if you made a uniformly textured wall out of both materials, you probably wouldn't know the difference on radar. But if a granite slope weathers into a very rugged profile because of the granularity of the material and if sedimentary slopes come out in a series of steps, perhaps there will be a considerable difference in their appearance on radar due to their geometry. Now this seems to me to show the subtle difference between the approach of an essentially radar oriented organization and an essentially geology oriented organization. Anybody caught in the middle as I was would realize that certainly the nature of the rock determines the nature of the geometry that you are going to get from the erosional processes. So, in a very real sense, Bill is absolutely right; granite does show different than sedimentary rock, even though you were to examine these rocks very objectively, say putting them in a box and running a radar over them, there is no difference. Now I'm not stating these things very categorically even though it may seem so, but I don't think we know enough about them. I believe that this semantic difference is something that we have to watch, but I'm not worried about it. I don't think that there is any real difference in meaning. I think that we have to get the words ironed out and get people to understand each other.

I think that the thing to do now is to let Bill tell you about some of his very fascinating work with radar photography. He has got a very unique approach and I think it will be of interest to us.

AN APPLICATION OF RADAR TO GEOLOGICAL INTERPRETATION

William Fischer

The Geological Survey is new to the sophisticated sensing field. In fact it is so new we haven't even started. I might say that our only contact with this type of work, has been in photometric and colormetric work on the surface of the moon, and prior to that, photometric and colormetric work on a number of test areas in the United States. These were restricted to the visible spectrum. In one area in New Mexico we have, infrared photography, color photography, color negative photography, and black and white photography at two scales. We did break out the component parts of the color, that is, the red, green, and blue parts of the spectrum into black and white photography. The reason for this introduction, is that each one of these photographs gave us additional information. There was none better than the other, they all provided something different.

What Bernie said is true. I knew nothing about radar photography and the only reason I agreed to attempt an interpretation is because it happened to pass over one of these areas. Bernie remarked to me that he wanted a pristine and naive view of the radar photography. To phrase this another way, I was to be the utterly stupid part of the statistical sample. We have no organization table to show you because we don't have an organization. Furthermore we do not intend to develop one. We have no charter within which to operate and I hope that we keep it that way.

Let me tell you about this experiment. The reason I didn't want Bernie to rub this illustration off the blackboard is because Walt Bailey declassified it this morning.

This sketch represents a radar photograph. I put on a very few of the multiple images that exist. Here is an area of drifting sands covering a very flat topographic terrain. These are some nobs of Pre Cambrian rocks. This is a plowed field within the area of drifting sand. The drifting sand appears quite bright and the plowed area and the surrounding terrain quite dark. There is no noticeable difference in topographic position. In other words, the sand

is thin as illustrated by the fact that it disappears when you plow the ground. I don't think this is a factor. Furthermore, this hasn't been plowed since the soil bank came in, so there is not a new accumulation of sand of any significance. So we have something to explain here. Why does the drifting sand appear quite white and why does the background residual soil appear quite dark? I don't know the answers. I'd like one.

This is a road and this is a railroad. From the conventional photography I don't think that the average interpreter would recognize that this is the railroad and this as the road, because of the configuration of the terrain and the fact that all the junctions are swept. On the radar photography the railroad is bright and the road is quite dark. I think this illustrates the type of interpretation that radar can uniquely assist in. It gives you a positive identification of the railroad.

This is a buried pipeline. It shows on the conventional photography as a straight pattern and on the radar photography it shows as an intermittent bright streak, and one might ask why this shows up. The answer that I gave was that in turning up the earth to bury the pipeline they exposed a ferruginous sandstone at the surface and this gave a little greater response than the limestone that existed elsewhere at the surface. There is a disturbance of the topography. It could well be that the bright return that we see is related to the texture of the ground rather than to the type of rocks. However, there are a series of mesas in this part of the country with the limestone on top and the sandstone underlying. Everywhere that the sandstone is oriented so as to be shown on the radar photography, the sandstone is brighter than the limestone.

There are a series of anticlines that come through here. In one of them the underlying sandstone is very near the surface. There is 100 per cent soil cover. It is brighter and it was my assumption that because the sandstone was at the surface the residual soil was of a different composition and therefore, it shows a brighter image. I don't know whether this is the true explanation or not. However, on this one which is also soil covered, there is nothing but limestone at the surface, covered by a thin layer of soil, and yet the crest of that anticline

has a brightei image than does the area surrounding. One interpretation that might be made is that you are getting some penetration of the soil and soil attenuates the signal less and you are getting some brighter image back. Whether this is correct or not I don't know.

These are two igneous masses. This has a very sharply defined boundary and it is Tertiary in age. So I think that the radar photography gives us a better measure of the weathering process that has taken place on these particular masses.

Perhaps of most interest is a densitometer profile that we ran across this line. This upper profile is a topographic profile showing the rock distribution in the structure in the area. The vertical scale is exaggerated 10 times. Now it is true that the igneous mass here has a different topographic form than do the sediments that adjoin them. However, we know of the existence of this dike only because we saw it in the field. There is nothing on the conventional photograph that suggests that it would be interpreted from the standpoint of topographic form. This is a "guesstimated" soil profile along the same line, showing the local thickening and thinning of the soil and I would assume that there is a smoothing of the surface that accompanies the thickening of the soil. The important thing is that this is the densitometer curve across the length of the traverse which is about twenty miles. Everything that has a value greater than this is igneous; underlain by igneous rock. Everything that has a value of an intermediate stage is underlaned by ferruginous sandstone. Everything that has a lesser value is either siltstone or is overlain by a thick residual soil. This is all I have to say.

STATEMENT OF THE PROBLEM TO BE CONSIDERED BY THE WORKING GROUPS AND SELECTION OF GROUP CHAIRMEN

Walter Bailey

This conference is being held as part of a study program that is being carried out here at the University of Michigan. This study program is supported jointly by the Army, Navy, and Air Force. Just over a year ago, people in the Office of Naval Research, Geography Branch, and people in the National Academy of Science - National Research Council felt that the technology of sensing was getting way out ahead of the application of this technology to the interpretation of the earth's environment. The gap is likely to get wider unless very stringent efforts are made to bridge the gap. This study program is one step in what I hope will be a continuing program over the years to make it possible for the earth scientists and environmental scientists to take advantage of the tremendous gain being made in the technology of sensing. This study program will serve to draw together the needs of the various fields of science for possible applications of remote sensors. This program will also serve to draw together information about the essential capabilities of the sensors, and their potential.

This conference is making a tremendous contribution toward the accomplishment of these things. This drawing together of information and presentation in suitable documents will serve many functions. These documents will serve to let people know, in perhaps a sort of a primer way, what the capabilities are, and what some of the interests are. This drawing together of information will make it much easier, I hope, for people in my position to try and promote the necessary funding. There are other agencies in Washington and other agencies scattered across the country which are sources of support. If remote sensing of environment is to receive the support that is necessary, these sources must be cultivated and they must be provided with the essential information. Reports coming out of this study program will help to do that.

Another thing I can mention here is the problem of security. Some have said in connection with remote sensing of environment that by far the most serious problem to be overcome is that of over-classification. Nobody would suggest that

anything be under-classified but they would suggest that reason prevail in the classification business. Yesterday a small group met to discuss security classification and we decided on two general approaches to the problem. One is, that we should make a piecemeal determined effort on an item by item, report by report, piece of equipment by piece of equipment basis, as seems appropriate and important, and try and work back through the services or classifying agency and attempt to get some declassification. How much success will be achieved remains to be seen but this is going to be pursued and pursued actively. Here again, it will help to have this drawing together of information because this demonstrates the importance for considering the problem of declassification.

The second approach that is going to be followed is a little hazy to me at the moment. I do know, however, that in Washington and elsewhere in the country in the last few years there has been quite a lot of talk about this problem of classification. Dr. Hoover of the National Academy of Sciences has told me that the Academy is extremely interested. To what extent the problem is coming to a head there I don't know. I feel sure that he will inquire and I believe that the remote sensing of environment problem and the associated problem of declascification can be made into a real good case. The present study program will continue into the middle of the summer and final reports presumably will be out toward the end of the summer. I am sure that in spite of all the words of confidence and pride that have been expressed in the work that is being done and has been done that everyone would agree that the effort is small compared to what should be done and that the opportunities before us are essentially unlimited. I think that we can take some heart in the fact that the efforts of which I have been speaking will be helpful in promoting the field of remote sensing of environment as a whole. I believe that where one portion gets successfully going that this would help in drawing another along and where we have in the past been dependent upon an occasional gust of emotion, occasional strong personal contact, and such things, I hope we can now get an atmosphere of large scale development.

The time in this conference has now come to shift gears very drastically. We have up until now, been talking primarily about what has been done and what can be done in terms of state-of-the-art. I would like for us now to turn to the question of the future and state the needs for research.

A group of us have met to discuss how the final hours of the conference should be conducted. There will be three working groups. The three groups will be: 1) meteorologists and oceanographers, 2) geologists and geophysicists, and 3) agriculturalists, botanists, and foresters. These three groups, I believe, will catch almost everyone. The chairman of the group composed of oceanographers and meteorologists will be Dr. Leipper. The chairman of the group composed of geologists and geophysicists will be Dr. Lattman. The chairman of the group composed of foresters, botanists, and agriculturists will be Dr. Shay. May I state again that the topic for discussion should be, the needs of your own group for research within the scope of remote sensing of environment.

REPORT OF THE WORKING GROUP ON METEOROLOGY AND OCEANOGRAPHY

Chairman: Dale F. Leipper

Well we had a very good panel meeting. We discussed some interesting subjects and listened to some things that had been done and could be done, as well as some that ought to be done. This panel was composed of Weiss, Garrels, Katz, Nobels, Polcyn, Hoover, Zissis, Fransecheni and myself.

We talked a little bit about general principles and we have three comments to make here. One is that probably no one of these techniques will be the ultimate method for any type of observation and that for any one quantity we will find that several techniques are useful, each one giving a different approach or different look at the particular variable. We feel that a lot of the lack of interest or the apparent lack of interest from meteorologists or oceanographers probably just stems from the fact that they didn't know what was possible. They may have never seen pictures taken at midnight, or they may not have known about some of the techniques which you have mentioned here in this meeting. In this light, we think it would be well if there would be a classified section, possibly at the next meeting of this group; and that everyone who takes part in the unclassified section be notified of the classified meeting such that they could try to get a clearance and try to participate in this meeting. Secret we feel probably would be the right classification level. Then they could actually see samples of data collected with these various techniques and they could go home that evening and start using them if they could. Well those are all the general comments; now some specific problem areas. We might take the first of those related to

the sea and consider the sea surface temperature. Well we don't know what sea surface temperature is--whether it is the temperature of the top molecular layer, the top millimeter, or the top centimeter--but we are interested in that. We understand that you can make measurements now with an accuracy down to about .2° Centimeter, and for certain uses this is perfectly satisfactory. We might for certain other uses such as small scale turbulence like to make measurements of small gradients. As a problem for the people in instrumentation, we will throw out the idea of sea surface temperature measurement from satellites. This is probably possible but you have the question of interpreting the readings taken through the atmospheric moisture field. This will give you some things to think about.

We have a problem in oceanography and meteorology; that is the problem of understanding what these temperatures mean and what can be done about them in regard to evaporation, exchange of energy, and so on. A different problem area is that related to sea state. This comes and goes but it looks as though in the future more information about the sea state will be quite essential. There are many ways you can get this. Possibly more can be done from the sea return on radar by using not the straightforward navigation radar but using radar scientifically as you mentioned this morning--changing frequencies, changing elevation angles, and various approaches of that sort. Also you might be able to do something with densitometer measurements (the sea changes its actual black and white shadings as it increases in state), with passive-active microwave techniques, or maybe with lasers; someone said you can shine a spot on the sea and then with a plane flying over, you can photograph something which you cannot get by any other method. Maybe by means of very sensitive altimeters, you can get something on sea state.

A third general field in oceanography you might classify as compositional properties, meaning properties of the surface waters; and one of quite a bit of interest would be salinity. As far as we know nobody has measured salinity by means of a remote sensor. This is simply the salt content of sea water and we need its variation just as we need sea temperature variations. It is related to density, rain fall patterns, distance from the coast lines; it is also an important variable in studying fish, or anything that lives in the ocean. It is related to all the movements. So can you measure for us the surface salinity patterns? I don't know how you might go about this.

Other properties under this particular topic of compositional properties are contaminant, organic population, carbon dioxide, and many others; all of these would be of interest. The techniques may be ultraviolet radiation methods. Not much has been done as far as we know. Maybe in CO_2 for example that would work. If you can give us the measurements of these properties we would try to use them to describe the mixing which goes on in the ocean--mixing of fresh and salt water, mixing of surface and deeper waters, mixing of radioactive materials. This is a research area then for the oceanographers and meteorologists. The deep ocean you realize is an average of 2 and 1/2 miles in depth, and it is dark and cold; and the only way that we can get down there now is with a long cable with instruments attached. If you can find some other way by remote sensing to measure the characteristics of the deep waters, we would like to have it. We do send buoys now which transmit back acoustic signals. We have bathyspheres which will go down at one spot, one time, if you prepare several months in advance; but if you could just survey one mile down and 100 miles in every direction and do it as you survey sea surface temperatures, it would be very valuable. We can mention a pretty good problem area and that's the use of

electromagnetic radiation to study the deep sea. This may be an impossibility. We have clues that at very long wavelengths, someone may be having a little success; but we don't know of anything really being done with long wavelength electromagnetics in the sea. We have the acoustic methods which are very heavily involved and most meetings about oceanography talk acoustics with everything else exempted. There was one classified session in California which studied the non-acoustic methods--the "unsound" methods of studying the sea. We might be able to get more from various variations of gravity and from the magnetic field. Some way to interpret these variations in the light of ocean properties would be valuable. We also need to know the shape, composition, the density stratification, and the layering of the bottom sediments. There are acoustical methods, seismic methods, but here again possibly you could develop something in radiation techniques at electromagnetic wavelengths; and we simply mention this as a possibility.

Now in the things that affect both the atmosphere and the ocean, we have the flow problem. From synoptic observation of the Gulf Stream, we know that this varies and over a week or a two week period, it will move maybe a 100 miles from side to side and form eddies which cut off and drift away. To understand the ocean circulation we need a picture of this circulation maybe every three days, something of this sort. You can't get it from ship observation, at least not very readily. If you could develop a technique for measuring the flow from airplanes flying over the area, this would be very useful. The temperature pattern is a great help on this, but you might also consider visual means as you can often see the edges of these currents. You might consider tracers of various sorts. Now the jet stream in the atmosphere, of course, is very important; and it changes very radically from week to week. Now if we could put some sort of tracers there and just have a map

that gave a full areal coverage of the jet stream, it would be very useful in forecasting. So that is the general problem area of flow.

If we go to some problems that are more specifically meteorological, one of these has to do with the moisture content in the atmosphere. One fairly simple thing, I think, you could get for us is the moisture content--the total moisture content of a vertical column. You might measure radiation from the sun through this column and by its variation find the method of getting the total moisture in the path. Even more desirable would be the vertical distribution of moisture throughout this column, and then you do begin to have problems. We need to know this though for all meteorological work and along with this the temperature variation with height. We can, of course, get these quantities by means of the radiosonde observation. This is very expensive and very time consuming; and we have only a few stations and get data at only a few points. Here is one area of observation where we might be able to fill in quite a bit by using remote sensors. Now under the heading of moisture content, we should also mention the rain areas. You might get these from satellites. The tops of clouds from under which rain is falling may have different reflective characteristics then those under which there is no rain, because in the first case you probably have turbulence and rising air; the other may be the opposite. Can you outline the rain areas by looking down on the clouds from the top? Then there are cloud characteristics and cloud movements and here we do have quite a capability through radar. Radar of different wavelengths outlines clouds, tells something of their density, and doppler radio will provide a method of giving you motions of atmospheric particles. Another quantity that we don't use much as yet but which might be very important has to do with electrical potential distribution. We can measure lightning discharges through spherics.

I don't know whether it is a familiar term: it is simply static which comes from turbulent areas, but what we would like to know is the potential field from which the lightning discharges grew. Maybe this could be done by some remote technique. Another very important thing is the characteristics of the earth's surface that affect the weather. Radiation is the big factor here; but we need to know from day to day snow cover, reflective characteristics of all the different surfaces, tree or forest surfaces and grassy areas, moist soils and dry soils, and how they change with the weather. Fog, for example, is very much dependent upon the surface conditions.

Well those were the problem areas that we outlined and I am sure that there are many more. These may not sound too specific, but basically we feel that there are some things that should be done. To review the measurements we would like to have: 1) measurements from satellites of surface temperatures, 2) the nature of clouds and cloud patterns, 3) the characteristics of surface waters of the oceans, 4) ocean chemical characteristics and their distribution, 5) movement patterns through tracer qualities and others of the large circulation features, 6) synoptic pictures of what goes on in the ocean and what goes on in the atmosphere, 7) the electrical potential distribution in the atmosphere, and 8) the radiation characteristics of the ground as it changes from day to day.

DISCUSSION

Floyd Elder: What about clear air turbulence measurements? The meteorologist knows the conditions under which clear air turbulence may occur, but the only way of measuring it is by the bumpiness of an airplane as it flies through.

Mike Holter: What about the possibility of using variations in refractive index as a measurement source?

[Comment: Dale Leipper describes clear air turbulence as quite a serious thing from the standpoint of air navigation.]

Floyd Elder: The weather bureau has a program to measure clear air turbulence with very sensitive radar; I don't think it's been successful yet.

Mike Holter: How about the methods they use in wind tunnels for making schlieren photographs.

John DeNoyer: I think some work has been done on this by acoustical means from balloons.

Dale Leipper: Here again something is needed which covers a large volumn of air and which would indicate the turbulence in it.

Bernard Scheps: The Air Force and Navy have studies of inversion layers in the trade wind areas and so forth. They are picking up a lot of meteorological data.

Dale Leipper: We would like to have a method where the observer just stands on the ground and shoots up a ray of some kind which draws him a pattern of all the inversions above him.

[Comment: Mike Holter describes a method involving small projectiles and the emittance of intermittent puffs of smoke which can be observed with a telescope.]

Dale Leipper: Maybe something more can be done with the condensation trails of airplanes. I think one way to make progress in an approach of this sort is if the people who know instrumentation can actually spend some time on an observational expedition or with the people doing research in meteorology. We often find that the people in these fields can never design instrumentation themselves. On the other hand, the people who design instruments, if they go out by themselves without oceanographers and

meteorologists, may not measure the right thing or recognize what they have gotten after they do make a measurement. I think this conference will serve a very valuable purpose in bringing the two kinds of people together, neither of which would be able to do the whole job.

REPORT OF THE WORKING GROUP ON GEOLOGY AND GEOPHYSICS

Chairman: Laurence Lattman

Our little group was the group on geology and geophysics. It consisted of about 15 or 16 people. At the beginning the group groaned and moaned once about security and then moved on to something profitable. We do, however, wish to go on record with the statement that we would like to see release to accredited scientists in industry, government, and the academic world, any and all information which could possibly be released with the confines of common sense. The other difficulty we felt that exists between the earth scientists and the use of remote sensors is lack of a technical background in remote sensors by the earth scientists. We felt that there should be available to them either training pamphlets or training courses such as the short course given at the University of Michigan in the summer. The earth scientist should be made knowledgeable, not of the details of electronics or the confidential information, but of the theory and the methodology of remote sensing by infrared, radar or any other means so that he could possibly bridge the gap to its applications. The biggest stumbling blocks from the earth scientist's point of view is his lack of understanding of how the image is obtained, what it means, and its limitations; some of which have been removed by those present at this meeting. The most important single general factor that we feel could be utilized to make progress in this field is to allow the earth scientists to design the experiment. In other words, to allow the earth scientist to pick the area to be flown, the conditions under which it would be flown, and all other information relative to the experiment. Thus the flight itself, other than the actual flight plan and operation of

the sensor instrument, would be under the control of the earth scientist. There would be, in other words, a feedback between the earth scientist and those people who were knowledgeable of and actually operating the sensor instrument. It would have to be a widely based group of earth scientists drawn from various fields of interest, including perhaps foresters, botanists, hydrologists, pedologists, petrologists, and mineralogists--a whole great group of people who would get together and select a test area. As a matter of fact, one gentleman already accepted the assignment of heading up such a selection committee. Bernie Scheps offered his time and services to be the operation focal point of such a committee which might be scattered all over the country and to be the coordinator of this group for the selection of an area. Later on when I get specific, I will mention some areas; but the important concept here is that the group which will do the interpretation and attempt to extract the information from the records made by the remote sensors should pick the area to be tested. It was pointed out, for example, that if an area is flown for which there is no existing soil map, the area may be flown in 25 seconds; but that the soil map might take 5 years to prepare. There are some areas in the United States for which modern soil maps have just been completed. It would seem logical, therefore, that since the controlling factor is time, that we pick and fly those areas for which modern ground information is already at hand. Another suggestion that was made was to publicize to the earth scientists this business of remote sensing, and we suggested that articles be written for GeoTimes. This is an American Geological Institute publication which receives circulation of 20 some odd thousand among earth scientists. This article will point out what remote sensing is, what is available in general, and how it might be used. We have two authors--Joe Morgan and Dick Ray. They bucked a little, but the committee rode rough shod over them and

appointed them as the authors of this article; and we are looking forward to its appearance. This committee was very strong fisted and I think we should give them a hand.

Another suggestion made in a general way was a central location for the accumulation, filing, and distribution of all emission and reflectance data. One suggestion was the National Bureau of Standards, which is an outfit ideally suited for this, into which would be funneled all information obtained anywhere on the reflectance and emission characteristics of natural materials and from which information could be drawn by investigators. In other words, this would be a central depository for all of this information which would be so basic to interpretation of remote sensing pictures. This could be any organization; the National Bureau of Standards was merely suggested. Another general suggestion made was multiple runs for reproducibility checks as a general convention. Planes operated by centers conducting research on remote sensing such as the University of Michigan use a particular airport--in this case the Willow Run Airport. The sensor-equipped airplane takes off time after time and passes over the same spot. Other planes doing this type of work at other institutions or military installations throughout the country pass the same spot. We thought it should be a standing or conventional procedure for the men on these planes to turn on their sensing equipment when they pass this point. Then every time that they made the run they would come back with a complete remote sensing record of the same identical terrain features. This would give us, by removing the variable of terrain, a chance to study other variables that change with time, meteorological conditions, time of day, height of plane, recording techniques, etc. In other words, you could check the reproducibility of the results over the same terrain feature and this would be as I said, a conventional operation. The operator would know that he would, for example, turn on his equipment as he

passes US route 50 for at least 30 seconds south of US route 50, and there would be no additional cost involved because the planes automatically pass this spot in their routine flight. Now as to the particular areas that might be studied, we talked about the necessity of the earth scientists designing the experiment, selecting the area, the time of year, and what have you. One of the areas we suggested was the area already studied by Bill Fischer in New Mexico. There is an area in New Mexico for which Bill Fischer and some of his colleagues have a complete record of multiple film-filter combinations in the optical wavelength and in the infrared. They have many, many types of photos, color and black and white, all flown over this area. There is, in other words, a large body of diverse information already in existence about an area whose geology is known. This, it seems to us, would be an ideal area to fly with some of these other devices: infrared scanners, radar, and any other sensory device to add to the already sizeable group of information. It seems to us that it would be pointless to fly a new area and discard all of the valuable information and efforts that have already gone into this New Mexico area. An optional area would be that which has been studied by Dick Ray in the Appalachians. This area is also known in great detail. In Fischer's area in New Mexico, we would be dealing, of course, with a dry region; and in the Appalachians, I gather beer would be served. Another area which could be studied in considerable detail would be somewhere near the Willow Run Airport. Now the University of Michigan group through its Institute continually flies over this area. This would be the area of reproducibility we are speaking of where we continually turn on the sensory devices over the same terrain. Geologists at the University of Michigan could pick an area near the end of the Willow Run Airport runway or within easy flight distance and the plane could be sent over that area at all times when sensory devices are being tested. It would probably be in

glacial or lake deposits. There isn't very much bedrock present around Michigan. If a large grant could be obtained to get a bulldozer, we could perhaps prepare an outcrop. Other areas which were mentioned include the Fort Huachuca and Wilcox Dry Lake areas. in the southwestern United States. Scheps' group has already set up a radar base in this area for check purposes. This area is flown repeatedly, and this would be an ideal area in which to fly many sensory devices other than just radar.

In the perhaps more esoteric and long range viewpoint, but still of considerable value were a couple of suggestions tossed off at lunch by John DeNoyer after the group had met. One was the possibility of flying over an area of active volcanism. Take, for example, the Hawaiian Islands. A routine flight could be conducted on a weekly interval, a monthly interval, or some interval selected. There is already a ground volcanological station on Kilaeua. If we kept flying this area, sooner or later we have reason to believe, that history repeats itself and it will erupt. We will then have a series of remote sensing records made over this volcano up until the time she erupts and after she erupts. Something may show on these records which might enable us to predict an eruption. An additional suggestion made by John was to fly over an area of active faulting such as California where the whole state is actively faulting. This could be over the San Andres fault or any of the other major faults there. We could then see if certain temperature features or stress relationship on either side of the faults can be determined by remote sensing up to time of actual release or change by movement along the fault. I don't know whether John hopes to predict faulting, but certainly we could find certain energy distribution factors if we could measure them in relation to the release of energy due to a fault. How much of it goes into seismic waves, how much to heat, how much to sound.

These are specific things, but the group felt quite strongly that certain immediate steps could be taken. One would be to set up immediately this central depository for emissivity and reflectance data at the National Bureau of Standards or some place else. Also, the group wanted to start working right away on picking the areas and designing the experiments; actually, we should select areas as soon as possible. That would be Scheps as coordinator. Also we want to get the article into GeoTimes to make known to the world of earth science just what has transpired. There will, I realize, be a release from this symposium; but GeoTimes has probably the widest distribution of any periodicals in the earth sciences. That is the article by Joe Morgan and Dick Ray.

Bill Fischer: I just wanted to comment that the selection of an area is something to be realized in the future. The area of New Mexico and the area in the Appalachians where things could be done immediately. This is not something that is being imposed upon you.

Laurence Lattman: No, I am sorry if I gave that impression. These were some areas where a great deal of ground work has been done. The scientific community as a group, as Bill points out, would probably be asked and a large group of men would be involved in picking the test areas in the future.

Comment: The forestry and agriculture people would like to suggest a publication and help select the areas.

Laurence Lattman: By all means. We were speaking from the viewpoint of the geologists and the geophysicists, but we also realize and it has been repeated many times through this symposium and it certainly is true, that this would be a cooperative effort of scientists in many fields. There exists a forestry panel group here, the third group; and

we did not go into this, but assuredly we would ask their advice when it came to picking the area.

Comment: I would like to suggest that articles be sent to the American Geophysical Union, Journal of Geophysical Research, and the Professional Geographer.

Laurence Lattman: Well any journal of wide circulation. This would not be a technical article that would appear in any of the journals which consider themselves pristine in regard to the technical content of their articles. This is not intended to be. It is intended to be an article written at a non-technical level; it would not be acceptable to many of the specialized journals, but it could nevertheless appear in such things as GeoTimes or as an editorial note in the Journal of Geophysical Research. By all means, I would guess in this case, the more journals the better.

Don Portman: When you suggest specific places for routine operations and specific tests of various sensor systems on a specific ground surface area, I think we make a serious mistake not to include the specific item of documenting the meteorological situation in more detail than has been commented. I suggest that these experiments be planned for specific meteorological conditions that can be documented in terms of heat transfer between the atmosphere and the earth. I've seen so many infrared pictures that have left people stimied simply because they did not document the heat transfer characteristics between the atmosphere and the earth, and they were unable to ascertain what was going on. They would take another picture sometime later and the thing would look different. You'll never thread this thing out without the appropriate information.

Laurence Lattman: This was brought out by the panel that meteorological controls would be one of the key factors. There is no question but what you are correct. I

think the panel was unanimous in feeling this way. The point the panel wishes to make is that the earth scientists, and we are including the meteorologists among the earth scientists, should control the experiments and assuredly the meteorologists would be one of the scientific groups that would have a large say in the control. The basic philosophy that we wanted to get over is rather than random flight and then presentation to the scientists with a, "here is what we've flown; what can you do with it? Let the scientists say, 'please fly this area and then we'll do a lot more with it!" This is essentially what we're after.

Don Portman: I only suggested let's fly this area; I said, please add, let's fly this area at this time and let's place more emphasis on meteorological conditions.

Laurence Lattman: I think I mentioned this that the time would also be one of the controls; I think it was implied. If I failed to convey it, I did not truly convey the committee's feelings. They did feel that way definitely--time of year, day, height, everything. They want total control over the experiment.

Comment: Suggest selection of marine water area as well as a ground area for a test site.

Laurence Lattman: We could bring the oceanographers into it willy-nilly by flying the coast line, but the point is, we were called "geology-geophysicists" and there existed an oceanography group. Anything that one of the three groups say obviously reflects on the other group.

William Wolfe: This is the right time to ask the oceanography group if they will start selecting appropriate areas for us.

Laurence Lattman: Scheps was appointed by us as coordinator. If it is acceptable to the oceanographers, please funnel your information to him on the selection of areas.

If each of these three groups fall in separate compartments, then we have met disaster. These three groups exist simply for simplicity and discussion, but obviously it is a coordinated effort.

Walter Bailey: This is as good a time as any to comment on these coordinated aspects. You say that we have three groups here, and it has been demonstrated in inescapable terms that coordinated effort is needed. This coordinated effort just won't take place without provision for coordinated effort. In other words, I'm suggesting that there needs to be an across the field strategy body. Coordination is a word for it, but it's more than coordination--a strategy body is needed.

REPORT OF THE WORKING GROUP ON AGRICULTURE, FORESTRY, AND BOTANY

Chairman: J. R. Shay

First I would like to say how gratified I am to meet all you people and learn of your activities in this area. I have been associated with agriculture for a long time, and I believe that Professor Lattman will agree that agriculture is one of the more developed of the geological sciences, and rather extensively applied in this country of ours. Consequently there is tremendous interest and tremendous need for improvement of surveys in agriculture. One of the very great needs is in the economics, acreage control and production of agriculture. The committee approached this problem with considerable humility because anyone who flies over this extensive Midwest and the tremendous agricultural regions of the far west is greatly impressed with the extent of this operation. He is also impressed with the potentialities of the airplane and airborne vehicles in giving more information about this operation. So we approached this with considerable humility and we are sure that we have not covered nearly all the ground. We will not make anything near a complete report of all of the potential studies or potential applications within this fascinating area of work.

We did believe, however, that for the immediate present we might encourage broad groups of studies. The first we might call a more basic study of the physiological and environmental properties of plants, that contribute to the physically measurable properties that we are interested in from the standpoint of remote sensing. We are interested in such matters as pigments and changes in pigment under different growth conditions among different species, water relations, changes in water relations and how these effect reflectivity and emissivity. These are truly basic studies which have not been undertaken on a

broad scale, but which have considerable promise. I believe from some of the measurements that Dr. Colwell has made, we can make use of reflectivity to measure rather small differences in water relations, in toxins, and in things that effect growth that we have not used before. Since these are studies in basic physiology, it seemed to us that we might encourage plant physiologists to take up work in this field and that possibly under our existing method of funding research the National Science Foundation or other large grant agency might well consider funding such projects. We do not actually have any existing agency of any magnitude that can support these studies on a large scale. At least we have not been able to find one.

Interest over remote sensing is high among agricultural workers for reasons that I mentioned earlier. They are committed to making surveys for example of the conditions of crops, on a monthly basis, all over the whole United States; and on these monthly surveys are based some rather major financial decisions. How much storage should we provide for the crops? What are the market prospects depending on the size of the crops? Other financial decisions are based on these estimates so they are important to the economy. Also acreage control programs are now very much needed and being applied in very wide scale. Surveys are needed on a county basis, regional basis, on a commodity basis, for this purpose, so interest is high. We will have no trouble of any of our land grant Institutions in finding willing hands to cooperate and participate in these studies on applications.

One thing that we need is species identification. As Bob Colwell told you yesterday, we would like to know the difference between the different small grains during the growing season--June and early July in our area. We would like to know from the forest standpoint

what the divisions are so far as species are concerned in our woodlots and in our forest stands. Secondly, we would like to know one other point here. Among our economic crops, we would like to know the degree of infestation of weed species. Now these species may be related very closely to the economic crop species as you know. Pigweed might be very hard to tell from soybean plant whereas giant foxtail might be very readily discerned from a soybean plant. I would hate to have to pick out a giant foxtail plant from a corn plant, or a Johnson grass plant from a milo plant. So we have got all degrees of difficulty here in picking out plant species. Another thing we would like to determine is the size of the plants, the height, and the crown diameter in the case of trees. Another thing that affects agriculture is the density of cover. Now this reflects many things--perhaps the degree of winter injury in small grains, in wheat, winter barley, or winter oats. What is the density of soil cover? It would contribute a great deal to predicting the yield of soybeans if we knew how much of the row, the middle row, was covered by the soybean plant. Another thing we would like to know is the condition of the stand. Is it damaged much by disease, by insects, or by nematodes underground? What is its vigor? This might be a reflection of moisture supply. It might also reflect the fertilization level. Finally, what is the stage of development of the plant at any given time when we are making this survey? Is it merely heading? Is it before harvest? Is it after harvest? What is the stage of development?

Now with regard to animal factors--there are some applications with regard to animals. It would be nice if we could determine, for instance, the number of cows on range, number of pigs in feedlots, number of cattle in Iowa feedlots. We would like to identify the kind of cattle--dairy types perhaps, from beef types. We would like to be able to differentiate between a fat hog and a calf. What are its physical dimensions?

Now with regard to soils--many of you are more qualified then we in this area; but some of the things of importance that we can think of are determination of soil types, the condition of the soil as far as moisture is concerned, physical composition including its particle size, the organic matter content (this would affect the heat emissivity I would think), color, slope of the soil, erodability, the depth of the tillable soil (especially in muck land).

Now what do we recommend as a group? I am going to speak broadly here for just a couple of minutes and then call on members of the committee that are more qualified than I to speak in this area. First, as far as the applied phase is concerned, I think that we would agree that we could divide our studies here into two types. First, the more intensive studies that might lead to more basic information; more widely applied information. We would like to see increased activity in making measurements of plants, plants in different condition, different species of plants, for their reflectivity and emissivity; controlled measurements with spectrophotometers that may be in existing laboratories or may be made available, or with equipments that may not be in the laboratories at present but may be available in laboratories under security regulations. We would like to have this not only in the visual spectrum and in the near infrared, but over the entire spectrum. Measurements should be made on plants under different conditions. Second, we would like this extensive study in which we would go out with existing remote sensing equipment and in this area we run into security problems. Most of this equipment has been developed under security regulations. We would like to take the more advanced of this equipment--the best that you can give us--and work with you with it in plots that we have established and which we know about, and have you make measurements over these plots at different times of the

year and then let us help you interpret the imagery that you take. Now we could do it this way or we could set up a special project where we would hire agriculturalists or biologists to establish these plots, but at least at the beginning we might make use of existing personnel. As all of you know between the triangle you might draw say, from the New England states, to Chicago, to Washington, D. C., there must be some twenty or more land grant institutions, each of them employing somewhere from 75 to 250 biologists and agriculturalists--persons intensely interested in this field. These people in many cases have plots in which they know the history, not only of a particular season but also of previous years. Most of these institutions have experimental farms. They are thoroughly acquainted with the fertilizer treatment of previous years, the fertilizer treatment this year, and the variety of plants planted. They have got a high degree of variability in these experimental farms and this variability is known. It seems to some of us that we might take advantage of this in this area or in other huge agricultural areas where the same type of plot arrangements exist. We could sense these plots remotely by whatever devices we could organize and then if somehow we could arrange to help you interpret those images, we think we could point up a lot of problems in a hurry. This would tell us how far to go in the development of this as a research program.

Now I would like to call on Bob Colwell to ask him to elaborate on any of these points that he would like to; and then I would like to have Marvin Holter tell us more definitely of some of these intensive studies of plants that he would like to see done in the infrared; and Wendell Blikken for how to implement a field study on radar that might be helpful.

Robert Colwell: I expect most of you have heard quite enough from me, so I will make this rather brief. A bit of it will be repetition of what has been perhaps better stated, but I think that it is important to recognize the successive steps that we might logically go through and here is my attempt at summarizing this.

First, we should decide on the list of objects and conditions that we wish to identify. If this is just from the agricultural standpoint, we select a test area on the basis of this; but at each time we should consider whether we can get information of interest to geologists, oceanographers, and so forth. I would emphasize that what I visualize as needed initially is not 100 test areas; it is not state-wide coverage with all these sensors; it is a local area for which you know ground truth by having lived there, day after day for a period of several months, if we are talking about agricultural crops, or an area that you know the geology of as clearly as Bill Fischer and Dick Ray know some of these areas that they are considering for tests. Once we have selected this area, provide the objects and conditions we are interested in, we can simulate these by manipulation as necessary. Then we would go ahead and conduct our remote sensing with all of the variety of sensors that need to be used; but before we did this, we could probably make that step a little more intelligent if we tried to find out what the energy returns will be within those portions of the electromagnetic spectrum for each of the objects and conditions we wish to identify. If we had these curves of energy return as a function of object, wavelength, by wavelength, then we could pick out the blips and pips wherever the object or condition we are interested in shows a unique energy return. Having done that, we would hope to pick a sensor that is sensitive in that part of the spectrum; and we would also attempt to pick a filter which would screen out any other parts of the spectrum to which this sensor is also sensitive, but which parts are not wanted

because they would decrease the signal to noise ratio. Then if we had all this material in hand in the form of imagery of one kind or another, we would consider the job was done. I based this on what has so often happened in the past in the few projects I have been connected with where it is such a hardware problem to get through this sensing phase that everybody starts dancing for joy as soon as all systems go and they get an image. Without any facetiousness at all, it is the general pattern to wait many months or even many years before you get over that celebration and get out there on the ground to find out what the imagery shows. Now particularly with reference to Dr. Shay's committee on agriculture, you need to get out there the same afternoon or if you can't do this, then the next morning and find out what the situation is. It is for this reason, mainly, that I say that it is more important to have a small area where you know ground truth intimately and know quickly what to look for and see what might show up then to have the confusion of state-wide coverage dumped into your lap as obtained with 10 or 15 different sensors. If I were to refine this suggestion any more, it would be simply this: wouldn't it be nice to have this test area say forty acres in size with twenty acres in which you had manipulated things just as you pleased, and another twenty acres where a guy unbeknownst to you did similar kinds of manipulations but you studiously avoided that area so you don't know what ground truth is there. You are handed all this imagery and you look first at this area that you have lived with and you come up with certain correlations and on this basis you say, "I predict that over here in the other twenty acres which I have not yet visited, you will have this condition here, this one here, and this one here, and then you go over to find out how wrong you were; and it's only by using foresight instead of hindsight that you may have a sobering experience as to the limitations of this system. Now once you have decided which imagery works and which sensors

work, you then have just two steps left as I see it. One is to write the specifications for the people that are going out to do the reconnaissance job to gather this kind of information for areas you are interested in for future missions. You have to tell them as many of these things as may be pertinent to the particular mission, what wavelengths to use and, therefore, what sensors to use; what filters to use; time of day; what angle; what scale of photography or other imagery; and season of the year; things like that. These are all the specifications. The other thing is to prepare some kind of reference material that the image interpretor can consult so that he will have some idea of what this imagery is all about. And if you try giving him all these clues just in a lecture fashion, he will soon weary of all this; but if you can prepare some kind of little reference manual that shows examples of how a certain crop looks with a certain disease, or how a certain area looks just before an earthquake or whatever, then he can compare the imagery that he later is called on to interpret of area X with these examples that you have compiled for him. And it takes more than just publishing a bunch of photographs unannotated. The real service here is to indicate exactly what the clues are that you found useful on this imagery and point to them. Now it doesn't follow that once you provide this you can take any grammar school boy as was mentioned earlier and give him this dictionary or reference key and he can do as good a job as the professional agriculturalist or geologist who has worked on this problem for 20 or 30 years. I submit, however, that even the professional can profit from this kind of reference material. Now if you really are concerned in this group about the kind of guy to select to do the image interpretation, more power to you. I think that this whole thing can still fall flat on its face if we did all the things I have just suggested or improvements of these, and then just handed it over to any old image interpretor. I think that we should select these

fellows on the basis of visual acquity, if it appears necessary to have this the basis of interest, the basis of background in the discipline that they are trying to extract information regarding, and give them the proper training once you have selected them to go ahead and use these sensors. If I seem particularly sensitive about these last points, I will conclude with this one specific example. A couple of wars ago I happened to be in charge of photo intelligence for the Okinawa show. They sent 100 image interpreters to do the job which in affect could mean life or death to 100,000 troops. Do you know how these image interpreters were selected? I don't care if this thing is on, I will tell you. Most of them were selected on the basis of whether or not they had flunked out of the course in which they were to learn how to interrogate German prisoners of war; and if they flunked whether they had one eye ball, two, or three, they made photo interpreters out of them and sent them to the forward area. Now this is a pretty serious charge and it is a mighty important one; and it's pretty obsolete except I don't think we have learned a whole lot since to improve our knowledge of what might be done.

J. R. Shay: Marvin would you give us a bit more detail about plant emissivity and reflectivity in the infrared?

Marvin Holter: Actually I want to talk about the whole spectral region not just infrared. These problems when approached from the point of view of the user look to me, as a sensor type, unbearably complicated. I think it turns out that there are some features of at least one group of the sensory equipment which will hopefully let us simplify what we might start doing here. Now I am talking only about the electromagnetic sensors at the moment because the people of our group were interested by and large in foliage and we didn't consider too seriously acoustics and some of the other things. So we distinguish

about half a dozen spectral regions: ultraviolet, visible, near infrared (out to about 1 μ where one can use photography), intermediate infrared out to about 14 μ, millimeter radar, and centimeter radar. Rightly or wrongly, we didn't consider longer wavelengths for foliage applications. Now from the sensor point of view at any rate , things look a little simpler because an electromagnetic sensor cannot distinguish very many characteristics in the incoming radiation; not more than four, as a matter of fact--wavelength, amplitude of the signal, in some cases phase angle, and with some equipment polarization. So this looks a lot simpler. Now whether the devices are active or passive, there are a very small number of the features of the foliage which can really influence any of these things here. These are principally the reflectivity and the emissivity of things that we are looking at. To people interested in foliage, these will be most strongly a function of two things--namely, health of a plant and possibly the age of a plant. So at least by this reasoning, we can reach the conclusion that in these spectral regions with this sort of sensor, reflectivity and emissivity turn out to be much more important than some of the other things that we might concern ourselves with. I might add here that we might distinguish between two types of reflectivity and emissivity measurements--microscopic as on a single leaf and a broader type which is gathered over many members of whatever population that we're concerned with. Under some circumstances the results are different when averaging over a large field of grain, let's say, than when we are looking at an individual leaf. Now before the "infrareders" in particular tell me that I have forgotten one of several thousand things, like temperature, I really have not. It is my assertion that in order to make the job manageable, we have to select some of the most important characteristics and start to work with those; and only when the conditions of the experiment indicate that we have to consider some of the

others, should we then start to worry about them. In order to get started, we need to select the variables of central importance; and at least for these kinds of sensors, these seem to be of major consequence.

SUMMARY

Walter Bailey

It is quite apparent from the discussions that have taken place over the last three days and in particular, from the reports offered by these three work groups, that several conclusions can be drawn regarding remote sensing of environment. One is that there needs to be a continuing effort on the listing of scientific problems which may be solved efficiently through remote sensing. This has to do with listing the objects and conditions to be identified. This is an activity that Dr. Leipper's committee pretty much confined itself to.

A second activity is the preparation of plans for implementation. Dr. Lattman's committee placed great emphasis on this. This might involve such things as tryout of existing equipment over areas where ground truth is known. The matters of practical implementation, or plans for implementation and such matters as recruitment were brought up.

A third thing that I might mention is that much more effective coordination of efforts and thoughts is needed; coordination not only among people in instrumentation technology and earth sciences but among the earth scientists themselves. At this point I would like to repeat again that there is a continuing need for some kind of national body for preparation of strategy and consideration of coordination.

Something that must be mentioned as a distinct and separate problem is the problem of security classification. This came up over, and over, and over again and it was the one single wet blanket on the whole conference. It is something that should be cured and anyone who has suggestions on how it might be cured ought to fire in those suggestions.

I think it can be concluded that the field of endeavor called remote sensing of environment has strength, vitality, and vigor. There are common interests here which need to be cultivated; common interests in terms of instruments, in terms of data interpretation, in terms of operation costs, and other things.

Another conclusion is that the University of Michigan study is on the right track.

Without taking more time, I would like to thank the distinguished participants and especially to thank the very able job of the work groups and commend them particularly for the efficient use of their time both in the committees and in the presentations. I should say that the people leaving here should consider this conference as a beginning, a stepping stone, a prelude if you will.

I believe there is the possibility of doing some work of spreading the word. One of the words that should be spread is that one of the most helpful things in getting a field of this kind on better footing is the preparation of good sound proposals, both of a formal and informal nature. I believe that supporting agencies would be most pleased to receive proposals.

Other Agencies Cognizant of the Remote Sensing of Environment Project

As an adjunct to the symposium as a means for determining the needs and potential for remote sensing of environment, letters of information about the project and its purpose were sent to the heads of geology departments at 54 universities and colleges in the United States and three in Canada (Figure 1). These represent, with very few exceptions, all institutions within the United States granting degrees in the geological sciences through the PhD level. A request was made that the letter be circulated among other earth science departments within the respective schools.

To date there have been twelve answering letters (about a 22% response). For the most part these letters have set forth the needs for various projects where remote sensors may have application or where feasibility should be investigated.

Suggested areas of investigation have included:

1. Recording of lake currents.
2. Measurement of snow pack thickness.
3. Temperature measurements of land surfaces.
4. A study of the reflectivity and emissivity of various types of earth cover.
5. Measuring solar radiation during winter months in remote areas in conjunction with ecological studies.
6. Study of the generation, mechanics and structure of severe storms.
7. Measurement of flame temperatures in forest fires and post-fire surveillance.
8. Measurement of altitude and thickness of rock beds and positive identification of rock type.

Figure 1

List of Universities and Colleges Receiving Information About the Remote Sensing of Environment Project

New England

Yale
M. I. T.
Boston U.
Harvard

Mid Atlantic

Princeton
Rutgers
Columbia U.
Cornell
Rensselaer Polytechnic Inst.
Lehigh U.
Pennsylvania State U.
U. of Pittsburgh

South Atlantic

John Hopkins U.
U. of North Carolina
V.P.I.

East North Central

U. of Chicago
U. of Illinois
Northwestern U.
Indiana U.
Purdue U.
Michigan State U.
U. of Michigan
U. of Cincinnati
Ohio State U.
U. of Wisconsin

East South Central

U. of Tennessee

West North Central

Iowa State U.
State U. of Iowa
U. of Kansas
U. of Minnesota
Missouri School of Mines
U. of Missouri
Washington U. (St. Louis)
U. of Nebraska

West South Central

Louisiana State U.
U. of Oklahoma
Rice Institute
U. of Texas

Mountain States

U. of Arizona
Colorado School of Mines
U. of Colorado
U. of New Mexico
U. of Utah
U. of Wyoming

Pacific States

Calif. Inst. of Tech.
U. of Calif. (L.A.)
Scripps Institute of Oceanography
U. of Southern California
Stanford U.
U. of Oregon
Washington State U.
U. of Washington
U. of Alaska

Canada

McGill
Queen's University
U. of Toronto

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Inst. of Science and Technology, U. of Mich., Ann Arbor
PROCEEDINGS OF THE FIRST SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT. 13, 14, 15 February 1962. Mar 62. 149 p. incl. illus.
(Report No. 4864-1-X
(Contract NOnr 1224(44)) Unclassified report

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Detection
Environment
Sensing

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